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A COMPARATIVE STUDY OF GLACIAL TILL PARENT MATERIAL IN WEST-CENTRAL ALBERTA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A comparative study of glacial till parent material in west-central Alberta" submitted by Alvin G. Twardy, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Soils developed from glacial till deposits in west-central Alberta present soil mapping problems because of their somewhat similar field morphological characteristics. These include the Cooking Lake, Breton, Hubalta, and Lobley soil Series which are all developed on till and are classified as Gray Luvisols in the Canadian Soil Classification system.

This study was undertaken to determine whether or not the separation of these soils into different Series was justified on the basis of differences in the lithology, fabric and composition of their parent materials. A further objective of this investigation was to determine whether or not random till samples from west-central Alberta (Chip Lake map and adjacent areas), could be correlated with any of the four glacial till parent materials under consideration.

For the investigation, representative till samples of the four soil Series were selected, as well as random till samples from the Chip Lake map and adjacent areas. Physical, chemical, mineralogical, and micromorphological analyses were conducted in order to characterize and study differences in the glacial tills. Duncan's new multiple range test was used to evaluate statistically the laboratory analyses.

Analyses indicate that physical, chemical, mineralogical, and micromorphological differences are evident in the Hubalta, Breton, Cooking Lake, and Lobley tills. The Lobley till is characterized by a higher limestone content and higher calcium carbonate equivalent than the other three tills. Amphiboles and high grade crystalline metamorphic and igneous pebbles are absent in the material. A greater quantity of total sand, coarse sand, and amphiboles permits the separation of

the Cooking Lake till from the other three tills. Penetrometer and bulk density determinations indicate that the Cooking Lake is the most compact of the tills studied. The Hubalta and Breton tills are found to be somewhat similar. However, the Breton till is coarser textured and contains a greater content of montmorillonite in the clay fraction. Micromorphological examinations show that the Hubalta and Breton tills contain weakly oriented skeletal coatings.

The analytical data suggests that the separation of the four soil Series is justified.

The till in the Chip Lake map area generally is similar to the Hubalta till, however some intergradation of the four tills is evident.

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I. INTRODUCTION

The delineation of soil boundaries between heterogeneous soils for their separation into mapping units is a problem which confronts the pedologist. In the field, situations often arise where such differentiation is extremely difficult, especially with soils having similar morphological features developed from genetically similar geological materials but with somewhat different lithology. Soils developed from glacial till deposits in Alberta, present such problems. Many of the soils developed on glacial till are classified by pedologists into different soil Series within the same Sub-Group, based on differences in fabric and lithology of the parent material. Four such Series within the Gray Luvisol Great Group present problems in differentiation. These are the Cooking Lake, Breton, Hubalta and Lobley Series. Although the Lobley Series is a Bisequa Gray Wooded soil while the remaining three Series are Orthic Gray Wooded soils, separations are primarily based on differences in parent material. These differences are believed to reflect characteristics of the local bedrock (Peters, personal communication). This is substantiated by Bayrock (1962) who found that, in general, the tills of east-central Alberta contain 80 to 85 per cent local bedrock materials in their composition and fabric. Only minor differences are noted between the sola of the four Series, and when these soils occur in interrelated landscapes, separation becomes very difficult. Such a condition exists in the Chip Lake map area (83G, W 1/2). A reconnaissance soil survey in the area has shown that separation of the four Series cannot be readily made, even though the soil Series had been previously mapped to the south and east of the map sheet.

At the seventh meeting of the National Soil Survey Committee of Canada (1968) a soil Series was defined as, "a three dimensional body such that any profile within the body will have either, a similar number and arrangement of horizons whose color, texture, structure, consistence, thickness, reaction, and composition (or a combination of these), are within a defined range or, in soils without horizons will have the differentiating properties, except thickness, within specified depth limits. The parent materials of all pedons in a soil Series should be reasonably similar in texture and mineralogical composition." A Series may be one or several soil pedons. Its differentiating characteristics are not necessarily identical or uniform in every respect but do vary within certain specified limits. These are generally determined by the scale of mapping.

The investigation of the Lobley, Hubalta, Breton and Cooking Lake glacial till parent materials (all of which are found in west-central Alberta), was undertaken to determine whether or not their inherent properties were sufficiently different to justify separation into different soil Series. The properties investigated included physical and chemical properties as well as lithologic composition. Of primary interest is the variability in the characteristics of glacial tills within the established soil Series as well as variability among Series. A further objective of this investigation is to determine if unknown till samples, from west-central Alberta, can be identified with any of the four till parent materials under consideration.

II. LITERATURE REVIEW

A. SOILS

The first attempt to treat soil science as an independent science, and soil as an entity in itself, was made by Fallow in 1850. His concept of soils included the decomposition and disintegration of native rock, with an admixture of organic materials. However the rock had changed and metamorphosed in its form and frequently in its makeup. Fallow as quoted in Joffe (1949) stated: "soil as such does not therefore belong any more to the rock formation, but is a formation by itself." Many other early workers attempted a more precise definition of soil, but the concept that the study of soils is an independent science was not appreciated until the time of Dokuchaev in 1880. To him is attributed the fundamental idea that "soil is a distinct independent, and a natural-historical body."

There are many definitions of soil and it is problematic whether any definition could be formulated to which everyone would agree. Fortunately there is no urgent need for universal agreement (Jenny, 1941). Joffe (1949), a representative of the Russian school of soil science defines soil as follows: "A natural body of mineral and organic constituents, differentiated into horizons of variable depth, which differs from the material below in morphology, physical makeup, chemical properties and composition and biological characteristics." The greatest drawback to Joffe's definition is that it excludes organic soils which have recently been added to the Canadian Classification System. A broader definition, such as the one stated

in the Soil Survey Manual (1951) would be more adequate. They define soil as "the collection of natural bodies occupying portions of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter, acting upon parent material, as conditioned by relief, over periods of time."

1. <u>Soil Forming Factors</u>

It remained for Hilgard in America and independently for Dokuchaev in Russia to enunciate the important discovery that a given parent material may form different soils depending on environmental conditions, particularly climate and vegetation.

In considering the processes involved in soil formation, it must be born in mind that two groups of processes are involved, namely 1. weathering and 2. profile development (Robinson, 1949). Joffe (1949) supports Robinson's view that processes of weathering and soil formation are not identical. He states that both of these processes have been mutually and simultaneously at work in creating the soil body, but long before this simultaneous activity, the process of weathering found expressions in disintegrating and decomposing the bedrock forming the mantle rock or parent material. Jenny (1941) does not agree that weathering and soil formation are two separate processes. He considers weathering as one of the many processes of soil formation, and thus no distinction between weathering and soil formation should be made. He further suggests that since weathering is controlled by moisture and temperature it follows that the formation of parent material also becomes a function of climate. If this happened parent material could no longer be treated as an independent variable and

therefore would cease to be a soil forming factor, but rather a part of the soil itself.

Dokuchaev proposed that soil is a result of the combined activity and influence of climate, vegetation, parent material, topography and time. Climate and vegetation are considered as the active factors of soil formation, supplying the energy for soil forming processes. Topography and parent material are the passive factors behaving as source or original material and distributing agent of other processes. Time is necessary in order for the factors to attain dynamic equilibrium (Joffe, 1949; de Sigmond, 1938; Jenny, 1941). Gravity, water (surface, soil and ground), and economic activity of man, are three additional factors of soil formation which Rode (1961) added to those established by Dokuchaev. Rode suggests that the eight soil forming factors should not be differentiated into passive and active factors, because the activity of individual factors are not similar in different soils.

The soil forming factors are not forces, causes or energies, nor are they necessarily environment. They have but one feature in common and that is that they are independent variables that define the soil system (Jenny 1941). For a given combination of the soil forming factors the state of the soil system is fixed and only one type of soil exists under these conditions.

2. Parent Material as a Soil Forming Factor

It has been realized for some time that many important properties of soils are inherited from the underlying rocks. Technical expressions like limestone soils or granitic soils are encountered in the

oldest textbooks dealing with the subject. They clearly convey the importance of parent material in soil formation.

Parent material refers to the unconsolidated mass from which the solum develops. The unconsolidated material directly below the solum is called the C horizon or parent material, only if the evidence suggests that at least a part of the solum is developed from material of the same kind (Soil Survey Staff, 1951). The parent material may form in situ from weathered rock (regolith) or may form in transported products of decay (Robinson, 1949). Jenny (1941) defines parent material as the initial state of the soil and thus avoids special reference to the strata below the soil, which may or may not be parent material.

The process of soil formation finds its greatest expression in parent material consisting of residual products of weathering (Joffe, 1949). It is obvious that variations in the lithology or fabric of parent materials may modify the process of soil formation (Joffe, 1949). Ehrlich et al (1955) are in complete agreement with Joffe's statement. They found that the composition of soil parent material has played an important role in determining or modifying certain types of soil profiles developed in Manitoba on sediments of Mankato age in the Wisconsin glacial advance.

Jenny (1941) and de Sigmond (1938) state that one of the prime factors in the transformation of a parent material into a soil with characteristic horizon differentiation is the downward movement of water. According to the regional concept of soil formation, all parent materials within a given micro-environment should produce soils that ultimately possess similar morphological features. However the speed with which the soil climax is reached varies enormously with the

constitution of the soil matrix, particularly with its capacity for water percolation. Joffe (1949) suggests that the depth of the soil profile is determined by the texture of the parent material. It is deeper on coarse than on fine textured parent materials. Ehrlich et al (1955) found that shallow profiles resulted when they were developed on excessively high lime parent materials regardless of texture.

The composition of the mineralogical elements exerts a profound influence on the process of soil formation. Quartz, orthoclase, microcline, biotite and muscovite are the more prominent minerals that persist much longer in the products of weathering than do other minerals (Joffe, 1949).

A study of five Orthic Gray Wooded profiles, in Alberta, developed on lithologically different glacial till parent materials was made by Pawluk (1961). The five soils could be separated on both their genetic and inherent mineralogical characteristics due to variability in degree of weathering and the composition of Upper Cretaceous pebbles in the parent materials even though morphologically they were similar.

Joffe (1949) reports that in the podzol type of soil formation, limestone parent material resists the reactions leading to podzolization. Ehrlich and Rice (1955) found that sediments in a similar environment, but with different quantities of lime carbonate show a decrease in weathering with increasing amounts of limestone. The percentage of inorganic carbonates in the soil parent material was one of the important factors that influenced the development of specific morphological characteristics peculiar to certain Great Soils Groups. It was suggested that parent material can cause differential development into Gray Wooded

and Podzol or Brown Podzolic soils and that it may also be responsible for the formation of Black Earths and Rendzina types in similar climatic and vegetative zones.

A preliminary investigation in the Athabasca Valley near Hinton, Alberta has shown the development of Brunisolic soils on a loess deposit in a Gray Wooded environment. The development of these soils has been attributed to the high lime content in the loessal material (Dumanski, personal communication).

Ehrlich and Rice (1955) found that greater decomposition of coarse sediments (2 to 50 mm. in size), in profiles of similar initial composition, occurred under forest than under grass vegetation. This is attributed to soil acidity which is suggested to increase concomitantly with the rate of weathering of rocks and minerals. Later Pawluk (1961) found that high active and exchange acidity showed little relationship to the degree of mineral weathering in profiles which were developed on glacial till. Weathering appeared to be more severe in horizons where acid conditions result from the presence of exchangeable aluminum. The exchangeable aluminum appeared to be an inherent feature.

Soil development is a dynamic process, therefore the degree of soil profile development will depend upon the length of time during which a specific parent material has been subjected to a specific combination of climate and vegetation (Hills, 1961). A change in either climate or vegetation may bring about, in time, a modification of the soil profile, but many of the characteristics of the solum are inherited features directly related to the underlying parent material.

B. GLACIAL TILL

Flint (1957) describes till as a direct glacial deposit which consists of a wide range of grain sizes. Dreimanis (1965) reports till as clastic particles, ranging from fine clay to large boulders and containing all the rocks and other materials that have been incorporated in the glacial ice during its motion. Thus the composition of till reveals the bedrock and non-consolidated sediments which have been overriden by glaciers on the way to the place of deposition (Dreimanis, 1965; Thwaites, 1963). The lack of obvious arrangement of its component particles shows that selective activity of water and/or air have played little or no part in its deposition.

There is no sharp dividing line between till and stratified drift, one grades into the other. Meltwater is present throughout the glacier and some of the finer grained rock material is flushed away during or even before deposition by the ice (Flint, 1957).

To some extent drift (till and stratified drift) can be classified according to the various topographic forms in which it occurs (Flint, 1957; Thwaites, 1963). Moraines, for example, are distinctive topographic features, yet they may include till and stratified drift in varying proportions. Drumlins, though topographically unique and composed mainly of till may have cores of bedrock and included masses of stratified drift. Accordingly topographic form as well as composition must be considered in any attempt to describe drift.

In the Edmonton area, till makes up most of the ground moraine and hummocky dead-ice moraine, and underlies most of the other glacial

deposits of the area (Bayrock and Hughes, 1962). The glacial till composition in both topographic forms was found to be similar.

Till is perhaps more variable than any sediment known by a single name (Flint, 1957). Pawluk (1961) attributes the variability in composition over extremely short distances to a complexity of factors related to ice mechanics and variabilities in bedrock erodability.

1. Till Composition and Variability

It is generally considered that the composition of most glacial deposits reflects the composition of the nearby preglacial rock formations (Forman and Brydon, 1965). Twenhofel (1950) reports that in any locality most fragments of till are of local origin.

Hort (1929) discusses in some detail the work of Hull and Russel who in a survey of the soils of Kent, Surrey and Sussex, found that their soil type boundary, coincided with the boundaries of the geological formations. However, texture is the main point considered as they state, "All of our experience in the field goes to show that each geological formation in the area under consideration gives rise to a distinct soil type characterized by its mechanical analysis." Westgate (1964) reported a correlation between the bedrock and till in the Foremost-Cypress Hills area in southern Alberta. He suggests that the texture of the tills is controlled, to some extent, by the underlying bedrock.

This oversimplified picture is sometimes contradicted by the fact that glaciers are known to have carried material for hundreds of miles (Forman and Brydon, 1965). Tills that overlie sediments close

to the edge of the Precambrian Shield usually contain large amounts of heavy minerals derived from the Shield. Gravenor (1951; 1957) demonstrated that the proportion of Precambrian material decreases as the distance from the Shield increases and at a distance of 180 miles the till contains approximately 14 per cent of Precambrian material. Harrison (1960) reports that Wisconsin till in central Indiana contains bedrock fragments which occur in excess of 1200 miles away. This type of study has shown that the most distantly derived materials have been ground up and appear in the fine sand fraction (Gravenor, 1951; 1957; Kruger, 1937). The decrease in rock type is attributed to wearing out of the rock and diluting by other kinds of rocks. In consequence, till, particularly the coarse fraction tends to take on the complexion of the local bedrock, and a single sheet of till can vary greatly in composition from one area to another. Hortie (1952) in a glacial till study in Alberta also found a greater number of minerals in the finer sand fractions than the coarser fractions.

Flint (1957) suggests that the proportion of a given kind of rock in till is controlled by at least the following factors:

1. Area of outcrop of the source rock upstream.
2. Erodability.
3. Durability in transport.
4. Distance of transport.

In a study of the heavy mineral content (SG>2.97) of till in eastern Alberta, Bayrock (1962) found that the heavy minerals make up about 1.7 per cent by weight of the total till and that the bulk of the heavy minerals were derived from Canadian Shield rocks. The local bedrock and Precambrian rocks contained 0.1 per cent and 8.7 per cent heavy

minerals respectively. It was suggested that the till in eastern Alberta contains approximately 80 per cent local bedrock. Statistical treatment of the results indicates that the surface till of eastern Alberta cannot be classified by means of heavy mineral assemblages. A very high percentage (95%) of the heavy minerals in the till were derived from the Canadian Shield. Kruger (1937) in a similar study reports that heavy mineral grains in all of the till in the Great Lakes region is strikingly similar to the distribution of heavy minerals in freshly crushed granites.

Jeffries and White as reported by Hortie (1952), and Buckhannan and Ham (1941) found the presence or absence of certain heavy minerals valuable in identifying parent materials. Roed (1968) in mapping the surficial geology of the Edson-Hinton area, in Alberta, found that Continental tills contain hornblende, pyroxene, kyanite and hypersthene whereas Cordilleran tills are characterized by an abundance of chloritoid, chlorite and epidote. He further reports that heavy minerals in the tills of the Edson-Hinton area are diagnostic of source area and support differentiation of respective map units. Kruger (1937) found that a number of Continental tills of different age, but all derived from the Keewatin ice center, had little difference in heavy mineral assemblages. In general, he reports that, garnet, hornblende and apatite are the prominent heavy minerals in Wisconsin Gray, Kansan Gray and Iowan tills in the Great Lakes region.

Bayrock and Pawluk (1967) found that the determination of trace elements such as iron, copper and zinc can be related to bedrock subcrop patterns in areas covered by glacial tills. Calcium oxide in addition to being related to bedrock subcrop patterns, also shows positions of significant glacial advances in northern Alberta.

The amounts of soluble carbonates and the assemblages of the heavy minerals may be correlated with the origin of the till and serve as a fairly satisfactory means for determining the various till sheets (Kruger, 1937). The mountain tills in Alberta, in general, have a higher calcium carbonate equivalent, than the Continental tills (Gravenor and Bayrock, 1965; Bayrock and Pawluk, 1967; Roed, 1968).

Gravenor and Bayrock (1965) report that tills have very little local variation in texture as shown by their work in the Wainwright area, however variations on a regional basis were found in Alberta. Tills of south-east Alberta are less clayey than those in east Alberta, which are less clayey than those in north-central and north-west Alberta. These variations have been attributed to the direction of ice advance, nature of the pre-existing glacial deposits and nature of the local bedrock. The tills in the Edmonton area are strikingly similar in texture to those found in the Alliance-Hardisty district in east-central Alberta (Bayrock, 1960; Bayrock and Hughes, 1962). This similarity is to be expected because of the similarity of bedrock composition.

The clay fraction of soil differs from silt mineralogically in that it consists of the secondary products of weathering which are not found in unweathered rock. According to Russel (1950) these secondary clay minerals rarely occur in particles larger than 2 microns and are much more resistant to weathering in the soil than are rock minerals ground to a comparable size. Grim (1942) reports that kaolinite, illite, montmorillonite, chlorite and sometimes halloysite have been found in soils. Many workers have found montmorillonite to be the major clay mineral present in Alberta soils. (Pawluk, 1961; Gravenor and Bayrock, 1965; Hortie, 1952; Forman and Brydon, 1965). Pawluk (1961)

found montmorillonite as the major clay mineral present in the fine clay fraction and illite the major clay mineral present in the coarse fraction.

The mineral chlorite occurs in eastern Alberta, but has not been found in significant amounts in the tills of northern Alberta. In eastern Alberta the tills sampled are underlain by Bearpaw shales which are known to contain chlorite. This in addition to the results of the heavy mineral studies suggests that the tills are largely local in origin (Gravenor and Bayrock, 1965). Bayrock and Pawluk, (1967) found that the mountain or Cordilleran tills have a much lower montmorillonite to illite ratio than adjacent tills of Keewatin origin.

Cordilleran tills in Alberta are generally stony whereas Continental tills are generally stone poor (Gravenor and Bayrock, 1965). Bayrock and Hughes (1962) suggest that the amount of stone present in till is variable and that stone poor till is usually present near lake borders. Bayrock (1958) thought that the relative abundance of surface boulders might give some information on glacial transport in the Alliance-Brownfield districts in Alberta. The results show that there is no obvious pattern to areas of equal boulder concentration, but that there is wide variability in the boulder content of till over short distances. Stoniness cannot be confidently used to determine the origin of a till since the stoniness probably depends on the composition of the underlying material and the ease of incorporation of this material into the ice. Roed (1968) suggests, however, that stoniness is of value as a descriptive term.

Krumbein (1933) states that local variations shown by the samples of till from a moraine clearly indicate that it is not safe

to base differentiation on a single sample. Even in the case of several samples the field relations must be carefully investigated, because local surficial material and varying drainage conditions may greatly effect the composition of samples in a limited area. It is necessary that a sufficient number of samples be analyzed to obtain the average composition of the till and thus eliminate local variations. Kruger (1937) reports that one should not expect to obtain a series of uniform sieve analysis from glacial material collected over a wide area. Heterogeneity both texturally and mineralogically, can be anticipated when working with till.

2. Theories on Till Deposition

In the second half of the last century an idea developed on the deposition of till which still prevails and influences markedly the thinking of many glacial geologists in the world------it is lodgment till. According to this concept, the glacier plasters on or lodges debris at its base while it is moving (Flint, 1957). It is difficult if not impossible to trace the development of this idea, but, nevertheless, it was formulated in 1894 by Chamberlin as stated in Flint (1957). The characteristics of lodgment till as reported by Flint (1957) and later Bayrock (1966) are:

(a) Most of the stones are oriented with the long axis parallel to the direction of glacier flow.

(b) The till is compact or hard.

(c) Crushing and abrasion of particles is intense.

(d) Horizontal fissility noted in places is attributed to the lodgement and the overriding effect of the glacier.

Heat is required to produce melting at the base of the glacier. The heat necessary to produce the melting is postulated to be firstly the geothermal heat and secondly, the heat of friction (Flint, 1957; Bayrock, 1966).

Lodgment till is plastered or lodged on to the subglacial floor and is deposited specifically from the under surface of a moving glacier. Basal till refers to the debris in the lower part of the glacier and is deposited from stagnant ice.

Ablation till is glacial debris which is deposited from drift in transport within or upon a shrinking glacier. During recession, ablation lowers the surface of a glacier until debris incorporated into it becomes exposed. It is envisioned that due to meltwaters running off the surface the ablation till is washed and becomes coarser in nature (Flint, 1957). Ablation till is generally thin, non compact and shows signs of slumping.

Gravenor (1955) elaborated on the ablation theory in order to explain the formation of prairie mounds or circular disintegration ridges. He postulated that as the ice becomes thin most of the incorporated debris ultimately becomes exposed on the surface where, through differential melting of the underlying ice, it is subjected to slumping ultimately producing prairie mounds. The difference between the original ablation till hypothesis and Gravenor's (1955) is that according to the latter the till may or may not be washed.

Woldstedt (1954) and Thwaites (1963) both accept the concept of lodgment and ablation till although they stress that ablation till is much more important than the former.

Unfortunately no really conclusive data is available as yet to decide the question of till deposition. Experimental work on glaciers

so far is generally concerned with the physical state of the glacier and not the deposition of till. The controversy of lodgment till and/or basal till versus ablation till cannot be solved by field data or mathematical computations alone. New criteria of differentiation between the different modes of deposition of till have to be established (Bayrock, 1966).

C. PREVIOUS WORK ON SOIL SERIES UNDER STUDY

The three Orthic Gray Wooded and the Bisequa Gray Wooded soils reviewed in this study are moderately well drained and developed from glacial till (Hortie, 1952; Pawluk, 1961; Peters and Bowser, 1960; Bowser *et al*, 1962; Lindsay *et al*, 1968). As previously mentioned, differentiation is made primarily because of the belief that the tills which serve as the soil parent material are of different lithological origin although no analytical data, as yet has been tabulated to substantiate this belief.

Lindsay *et al* (1968) describe the Cooking Lake profile as follows:

HORIZON	THICKNESS in.	THICKNESS cm.	DESCRIPTION
L-H	3	7.5	Deciduous leaf litter, partially decomposed in lower portion. pH 5.9
Ah	1	2.5	Black (10YR 2/1, moist) silt loam, granular, friable. pH 5.2. Often absent.
Ae	6	15	Light gray (10YR 7/2, dry) silt loam, platy, slightly hard. pH 5.7
AB	4	10	Pale brown (10YR 6/3, dry) clay loam, subangular blocky, slightly hard. pH 4.9
Bt	6	15	Brown (10YR 5/3, dry) silty clay, weak prismatic breaking to coarse blocky, hard. pH 5.6
BC	14	35	Yellowish brown (10YR 5/4, dry) clay loam, massive, hard. pH 4.8
C	at34	at85	Dark grayish brown (10YR 4/2-2.5Y 4/2) clay loam, till. pH 5.8

The above authors also describe the Breton and Hubalta profile characteristics as being very similar to the Cooking Lake profile. The

hard somewhat prismatic B horizon differentiates Cooking Lake soils from Breton and Hubalta soils (Lindsay et al, 1968; Bowser et al, 1962).

For ease of presentation the glacial till parent material of the four soil Series under study will be referred to as Cooking Lake till, Hubalta till, Breton till and Lobley till for the remainder of this thesis. The preceding names have no special connotation directed to profile development or to a specific type of profile.

Hortie (1952) suggests that the Cooking Lake till is compacted to a greater degree than the Breton till. It is believed that this compactness is inherited in the solum. The Hubalta till is somewhat finer textured than either the Breton or Cooking Lake tills (Lindsay et al. 1968), but there is little difference in texture in the Cooking Lake and Breton tills (Hortie, 1952). Hortie (1952) reports that there is little difference in the dominant minerals present in either the Cooking Lake or Breton tills but that there is a difference in the amounts present. Pawluk (1961) suggests that the Cooking Lake profile is more severely weathered than the Breton profile. Hortie (1952) found that the high amounts of weathered material, weathered feldspars and the possible presence of broken down collophane, in the Breton till suggests that this parent material is weathered to a greater degree than is the Cooking Lake till.

Pawluk (1961) found that the Breton and Cooking Lake soil at the location of sampling, have little local bedrock incorporated in their tills. The Breton till is underlain by soft Paskapoo sandstone however the quantity of the sandstone pebbles present in the parent material is relatively low. Numerous authors have reported that the Hubalta, Cooking Lake and Breton tills contain a few granite and

gneiss boulders derived from the Canadian Shield (Lindsay _et al_, 1968; Pawluk, 1961; Hortie, 1952; Bowser _et al_, 1962; Roed, 1968). The calcium carbonate content of the three previously mentioned tills is approximately 3 to 5 per cent (Lindsay _et al_, 1968; Bowser _et al_, 1962).

Roed (1968) in mapping the surficial geology of the Edson-Hinton area separated a total of seven tills. One of the separations, the Edson till, has been correlated with the Hubalta till (Roed, personal communication). He describes the Hubalta (Edson) till as follows:

> "It is dense, plastic when moist, medium to dark olive brown where oxidized and medium gray where unoxidized. It is stone poor to moderately stony, containing pebbles with a mode of 1 1/2 inches but with boulders up to 14" in diameter. Pebbles consist of metaquartzites, sandstone and shale from local bedrock and crystalline rocks of Canadian Shield origin, but limestones and orthoquartzites are not uncommon. Texturally the Edson till is mainly a clay, but the till consists of clay loam and loam at some localities. The calcium carbonate content averages 5 per cent."

Pawluk (1961) and Hortie (1952) found montmorillonite and illite the major clays present in the Breton and Cooking Lake tills. Kaolinite occurred in minor to trace quantities in the two parent materials.

Hortie (1952) could find no justification for separating the

Breton and Cooking Lake soils on the basis of their parent materials.

The Lobley soil differs from the previous Orthic Gray Wooded soils in that it is a Bisequa Gray Wooded soil developed on glacial till. A typical Lobley profile, as described by Peters and Bowser (1960) is as follows:

HORIZON	THICKNESS in.	cm.	DESCRIPTION
L-H	2	5.0	Loose leaf litter. pH 6.8
Ae	1	2.5	Pinkish gray (7.5YR 6/2, moist) silt loam, very fine platy, loose. pH 5.6
Bf	4	10	Yellowish brown (10YR 5/8, moist) silt loam, fine platy to crumb, very friable. pH 5.0
Ae	5	12.5	Light yellowish brown (10YR 6/4, moist) silt loam, platy, very friable. pH 5.7
Bt	12	30	Dark yellowish brown (10YR 4/4, moist) loam, medium to fine subangular blocky, firm. pH 5.2
BC	12	30	Yellowish brown (10YR 5/4, moist) loam, fragmental to fine subangular blocky, firm. pH 6.0
Ck	at 36	at 90	Olive (2.5Y 4/4, moist) loam, massive to fragmental, firm. pH 7.7

Except for the upper part of the solum (A horizon) the Lobley soil is morphologically somewhat similar to the Hubalta, Breton and Cooking Lake soils. The Lobley till is generally more olive brown and more friable than the other three tills (Peters, personal communication). The material is very stony, the stones being a mixture of smooth water-worn quartzites and fragmental pieces of limestone. This till has a fairly high calcium and magnesium carbonate content. The texture of the Lobley till varies from a sandy loam to a clay loam (Peters and

Bowser, 1960).

The profile depth is fairly shallow with lime generally at 24-36 inches below the surface in the Lobley soil, while the Hubalta and Breton profiles are deeper, with lime approximately 40-50 inches below the surface (Lindsay et al, 1968).

1. Underlying Bedrock Formations

Since glacial tills contain approximately 80 to 85 per cent local bedrock materials in their fabric and composition (Bayrock, 1962) the underlying geological formations are of considerable importance.

The Cooking Lake till was sampled in a region where the underlying bedrock formation is difficult to ascertain. The immediate underlying material appears to consist of the eastern extremes of the Edmonton Formation. Immediately to the east are the Bearpaw and Belly River Formations (Ower, 1958; Bayrock 1962). It is therefore quite logical to assume that the composition of the local material in the till is to some extent an expression of the beds of the Belly River and Bearpaw Formations as well as the lower beds of the Edmonton Formation (Pawluk, 1961; Bowser et al, 1962; Bayrock and Hughes, 1962; Bayrock, 1958). All the formations are Upper Cretaceous; the Edmonton being the youngest and the Belly River Formation the oldest. The lower Edmonton beds are largely comprised of interbedded non-marine, bentonitic, light colored sandstone and gray and brown shales. Iron bands and ironstone concretions are common (Ower, 1958; Bayrock, 1958). The adjacent Belly River Formation consists largely of bentonite, light gray sands and light or dark gray shales; but ironstone nodules, thin coal seams and carbonaceous shales occur. The Formation is non-marine and is

somewhat similar to the Edmonton Formation (Stalker, 1960). The Bearpaw Formation is a marine deposit consisting primarily of bentonitic, green, brown or black shale and minor sandstone (Stalker, 1960).

The Breton till is underlain by the basal Paskapoo beds characterized by massive crossbedded sandstones with some coal seams. The beds are generally grayish, brownish or rust colored. The material, in general, is coarser than that of the Edmonton Formation. It is of early Tertiary age (Paleocene epoch) and is a fresh water deposit (Stalker, 1960).

The Hubalta till also overlies the Paskapoo Formation and although it appears to have some colors from the Paskapoo in the rock fragments there does not seem to be much relation between the Hubalta till and the underlying basal sandstone beds (Lindsay et al, 1968; Roed, 1968). It has been suggested that sandstone only comprises approximately 25 per cent of the Paskapoo Formation in southern Alberta. The remaining 75 per cent being siltstone and shales (Carrigy, personal communication). Allan as quoted in Jones (1962), describes the Paskapoo beds as follows:

> "The beds are varied in character, but indurated and semi-indurated clays, clay shales, arenaceous shales, thin beds of hard and soft gray and ferruginous sandstones, and hard scaly, highly calcareous shales predominate. Laminae of coal and thin layers of lignite shales are common. There are certain beds of clay shales which absorb water and become soft, greasy, greenish muds."

The Lobley till is found in an area where the underlying bedrock is varied and complex. It has been suggested that the eastern

extremities of the Lobley till are underlain primarily by the Paskapoo Formation, but as one approaches the foothills to the west the Paskapoo Formation is tilted upward and a complexity of older bedrock formations are exposed (Canada Department of Mines and Technical Surveys, 1951). The older bedrock formations in the upper foothill and mountain regions west and northwest of Rocky Mountain House includes several formations from the following periods:

1. Upper and Lower Cretaceous.
2. Carboniferous.
3. Upper and Middle Devonian.

Thus the Lobley till can conceivably have characteristics of many bedrock formations.

The previous data on the geological formations suggests that there is a great deal of variability within a geological formation. Sandstone members as well as shale members are prominent in both the Paskapoo and Edmonton Formations. It has recently been suggested that there is little lithological and mineralogical difference in the Paskapoo and Edmonton Formations (Carrigy, personal communication). The Edmonton Formation contains a higher siderite and albite content than the Paskapoo. Hornblende and epidote as well as volcanic fragments are more common in the Edmonton Formation than in the Paskapoo, but in relatively small amounts (Carrigy, personal communication).

A formation is a bed or assemblage of beds with well-marked upper and lower boundaries. It is, in fact, purely a Rock Unit; and only if it contains appropriate fossils is it possible to say whether it represents a particular Age, or part of an Age, or even more than one Age (Holmes,1965). Stratigraphic members within a formation may be recognized and described as being somewhat lithologically different. Therefore glacial tills and

any overlying material derived largely from the local bedrock may reflect lithological variations. Accordingly till lithology may be expected to indicate the variations between members of a formation. For example, in the Swan Hills area of Alberta two soil Series are recognized within the Paskapoo Formation; one is derived from yellowish brown coarse grained sandstone (Modeste) while the other is derived from olive green shale (Pegastis) (Wynnyk, personal communication). Although both these soil Series are developed from members of the Paskapoo Formation they are inherently different with respect to their physical and chemical properties.

2. Continental and Cordilleran ice sheets

Numerous authors have reported that the tills on the plains region in central and northern Alberta, are derived from a Continental ice sheet which flowed southwest out of the Keewatin region during Wisconsin time (Gravenor and Bayrock, 1955; Roed, 1968; Bayrock, 1962; Bayrock, 1958). The Cooking Lake, Hubalta and Breton tills are all deposited by the Continental ice sheet (Lindsay et al, 1968; Bowser et al, 1962; Pawluk, 1961). Peters and Bowser (1960) report that the Lobley till is deposited by the Cordilleran ice sheet which came from the Rocky Mountains at approximately the same time as the Keewatin (Continental) ice sheet.

Gravenor and Bayrock (1955) suggest that the last principal glaciation in Alberta, the Wisconsin glaciation, has indicated directions of advance as shown on Figure 1.

Examination of the directions of advance show that the glacier which moved out from the Keewatin centered ice mass, crossed northern and central Alberta in a southwesterly direction. In western Alberta,

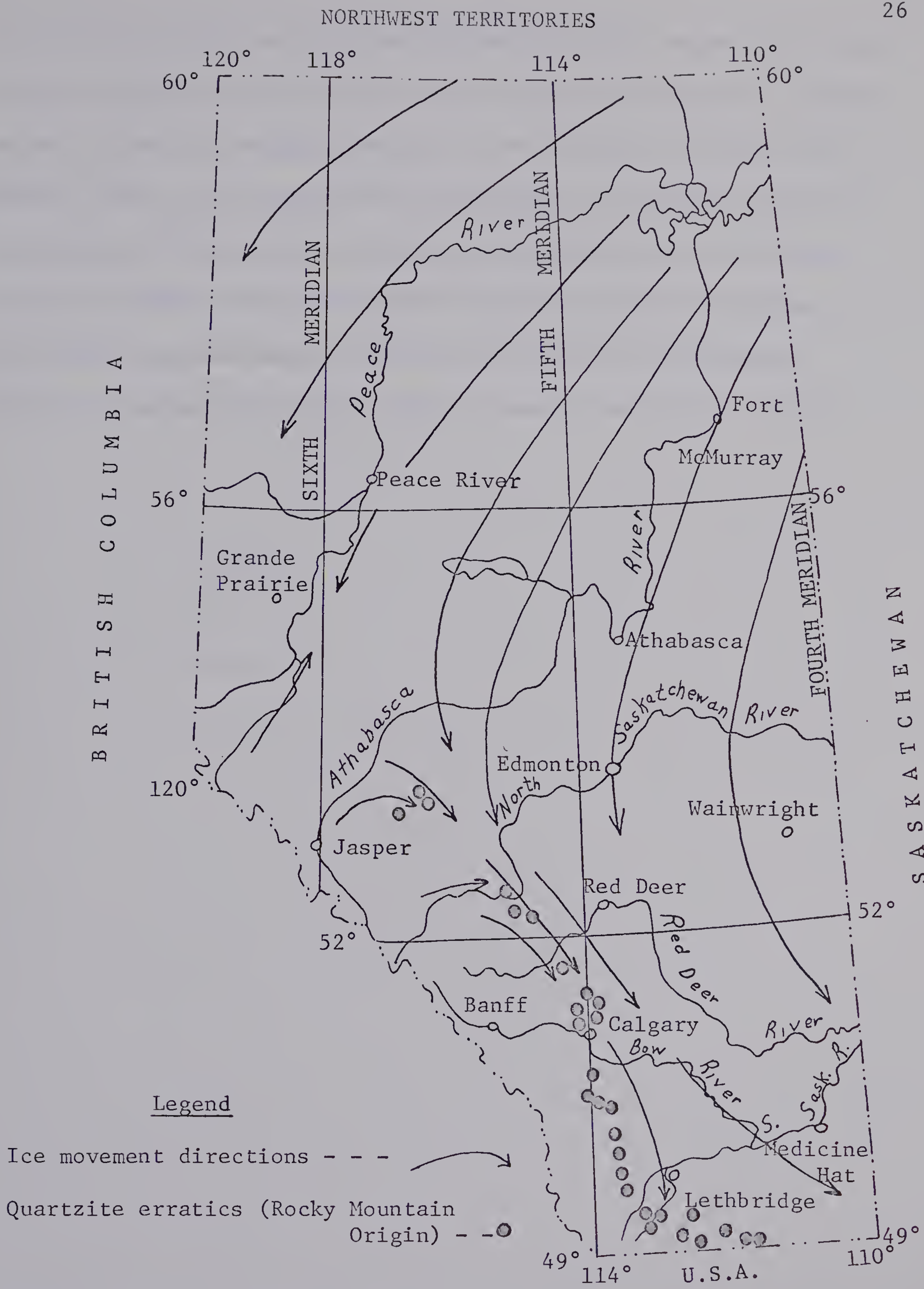


FIGURE 1 Generalized ice-advance directions in Alberta
Gravenor and Bayrock, (1955). (Reproduced with author's permission.)

the Keewatin glacier met the Cordilleran ice, which moved out of the mountain passes, and the two ice masses joined and flowed in a southeasterly direction roughly parallel to the foothills (Gravenor and Bayrock, 1965). The suggested southeasterly ice movement direction in southern Alberta is derived from the distribution of quartzite erratics (Stalker, 1956; Roed, 1967) and also from the altitudes of the highest glacial deposits from the last ice in southwestern Alberta and around the Cypress Hills (Gravenor and Bayrock, 1955).

D. TILL DIFFERENTIATION

The most outstanding characteristics of till is its lithological and physical heterogenity. The absence of sorting and, in general, of stratification as well as its compactness are the most obvious parameters that characterize till. Others are structure, lithology, color, and depth of weathering and leaching. Both field and laboratory examinations are required to evaluate the essential parameters of till because some properties are a function of the mass of the material _in situ_ whereas others pertain to component parts of the material.

The classification system used by pedologists is a natural, or taxonomic system based on Dokuchaev's statement that all soils are independent, sub-aerial, natural bodies with properties reflecting the effects of local and zonal soil-forming agents. Therefore the pedologist is interested in all parameters that may reflect the characteristics and properties of the soil body with reference to taxonomic classification as well as its performance in use by society. Odynsky and Newton (1950) consider parent material and position as the most important factors affecting the development of soils, in any one zone. Soils formed on similar parent material have certain common inherited characteristics. They usually form a specific landscape pattern in which positional differences largely determine the kind of profile that has developed on that parent material. Groups of soils developed on similar parent material in a drainage sequence are called "soil catenas", whereas the individual soils which make up that catena are called "soil Series". The number of soil Series shown on a map is governed largely by the detail of mapping.

There are few maps on lithology of soil parent materials largely because of the difficulty in obtaining detail; for example, the separation of strongly calcareous till from weakly calcareous till or saline till. Nevertheless such information is essential to the pedologist. Pedological maps are taxonomic or based on a natural system of classification, where all relevant characteristics and properties of both soil and parent material are considered in adapting soil individuals into mapping units.

Technical maps, prepared by various agencies interested in land-use, are only concerned with those characteristics and properties important in specific use, to meet certain objectives. A soil-fertility specialist would probably select properties such as available potassium, phosphorous, nitrates etc. An irrigation engineer would focus attention on factors relating to water permeability and water retention; a road builder would classify soils according to clay content, plasticity and properties connected with swelling and shrinkage. In other words, the choice of properties is determined by practical considerations. Engineers maps are largely technical, based on specific use, and therefore all parameters of the soil body are not considered. Glacial geologists generally produce genetic maps, that is, materials are separated on a basis of origin, or perhaps on geochronology.

SUMMARY OF LITERATURE REVIEW

A reconnaissance soil survey in the Chip Lake map area (83G, W 1/2) has shown that the separation of the Hubalta, Lobley, Cooking Lake and Breton Series cannot be readily made, even though the soil Series had been mapped previously to the south and east of the map sheet. The Lobley till is differentiated from the other three tills mainly because it is deposited by the Cordilleran ice sheet. The Hubalta, Breton, and Cooking Lake tills are deposited by the Continental ice sheet and are differentiated by Alberta Soil Survey mainly because of different underlying bedrock formations. Numerous authors have described the Edmonton and Paskapoo Formations as being similar lithologically. The variability within each bedrock formation is high, since both geological formations contain sandy members and silty or shaley members. Therefore separations based on underlying geological formations may be questionable. The dissection of the landscape, in preglacial time, by drainage could conceivably expose different members within a formation and thus give rise to a distinctly different type of till upon the same formation. This is thought to have occurred with the Hubalta till, which is underlain in the majority of cases, by the coarse textured soft basal sandstone beds of the Paskapoo Formation in west-central Alberta.

Bayrock (1962) has reported that till contains 80 to 85 per cent local bedrock materials in its constitution and fabric in east-central Alberta. Pawluk (1961) on the basis of a few profiles has shown that the Cooking Lake and Breton tills have small quantities of underlying bedrock incorporated in their tills. The Breton till east

of Breton, is underlain by soft Paskapoo sandstone; however the quantity of sandstone pebbles present in the parent material at the sampling site is relatively low. Hortie (1952) suggests that there is little difference in the physical and mineralogical characteristics of the Breton and Cooking Lake tills examined, even though the two tills are underlain by different bedrock formations.

Surficial geological maps have been produced in the Chip Lake and adjacent areas, but these are mainly of the genetic type in which origin and deposition of materials are separated. There are few which are based on lithological separations. Roed (1968) in mapping the surficial geology of the Edson-Hinton area separated seven glacial tills several of them based on lithological differences.

In conclusion the glacial tills in west-central Alberta have received little attention in the past. Little difference was noted morphologically when these soils were mapped. Separations based on the underlying geological formation does not seem warranted, and the effect of the underlying bedrock on the till seems to be questionable among various authors. The separation of the four glacial tills under study may not be justified if no mineralogical and/or lithological differences are found between the tills, regardless of the underlying bedrock formations.

III. MATERIALS AND METHODS

SAMPLE AREA

A total of 46 glacial till samples were collected, in this study, in various parts of west-central and central Alberta. The Cooking Lake till samples were collected in the Cooking Lake Moraine, east of Edmonton, near Elk Island Park. The Lobley till samples were collected near Rocky Mountain House. The Breton and Hubalta samples were collected in the Breton and Chip Lake areas respectively (see Fig. 2). The Hubalta till consists of 7 representative samples while the Breton, Lobley and Cooking Lake tills each consist of 5 representative samples. The remaining 24 samples were collected in the Chip Lake map area (83G, W 1/2) and adjacent areas in west-central Alberta where it was thought the 4 tills occurred (see Fig. 3).

Samples were collected in the summers of 1966-1967, while conducting a reconnaissance soil survey in the Chip Lake map area. All samples were taken from the C horizon, below initial effervescence with cold dilute HCl or, if no effervescence occurred, at approximately 6 feet. At each sampling site the following samples were obtained:

1. A bulk sample consisting of approximately 50 pounds of till.
2. Four Uhland core samples for bulk density determinations and thin section preparation.
3. Approximately 350 stones for pebble counts.

At 7 of the sampling sites representative of the 4 tills under study, a total of 12 Shelby cores were taken. These were sealed in the Shelby tubes with plastic bags, to prevent moisture loss, and taken

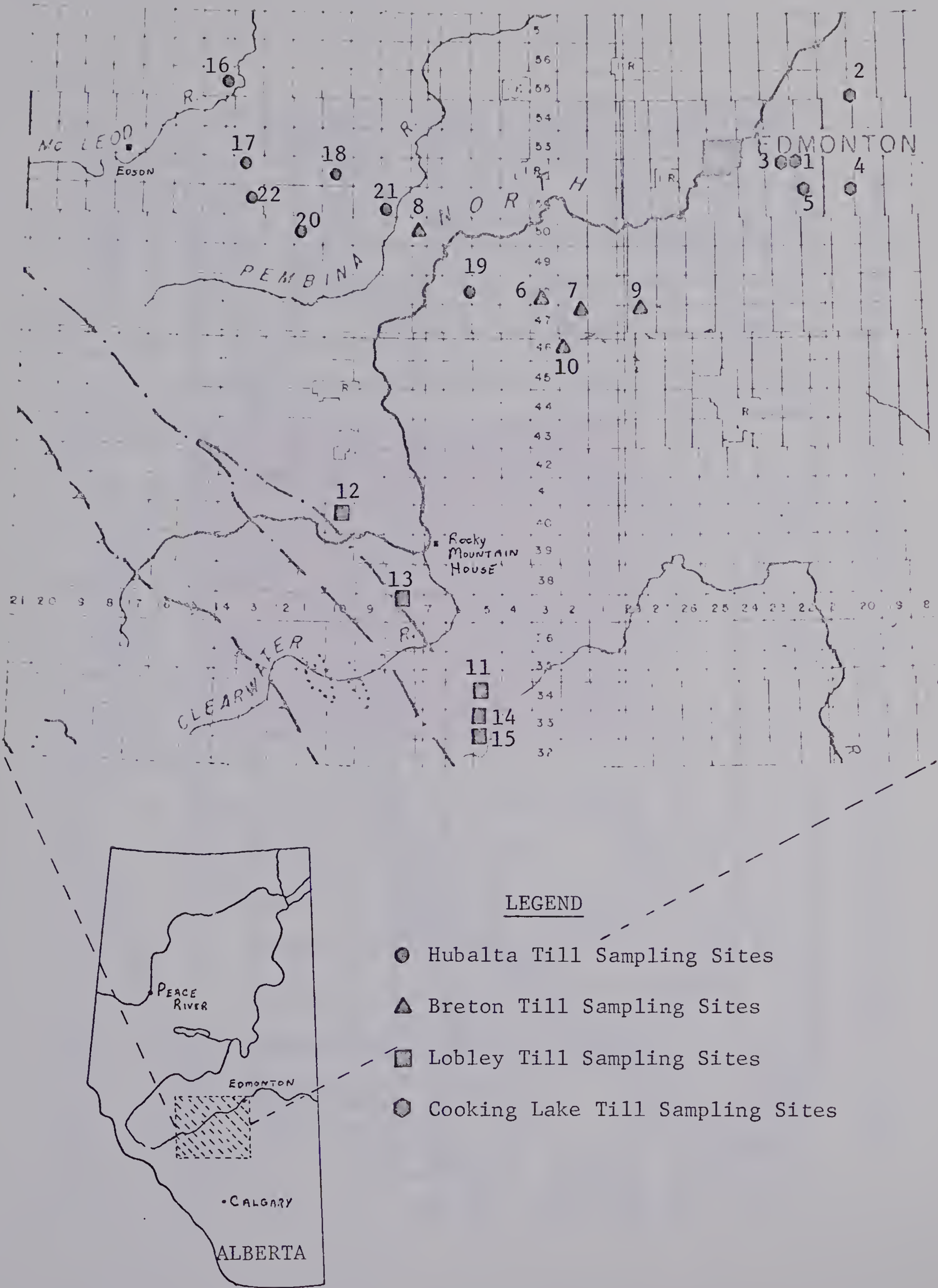


Figure 2. Map of the Hubalta, Breton, Lobley, and Cooking Lake Till Sampling Sites

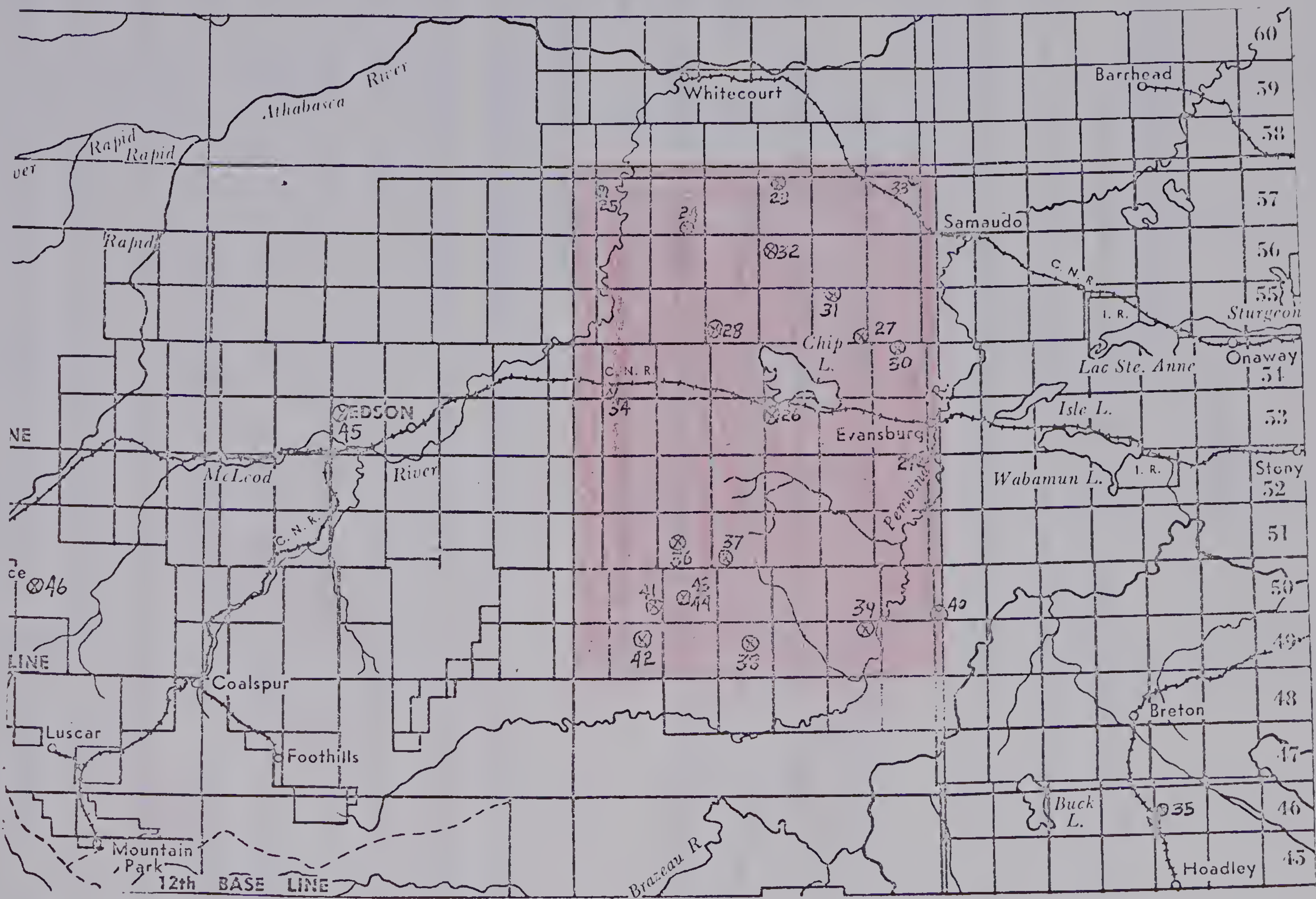


Figure 3. Map of the Till Sampling Sites in the Chip Lake and Adjacent Areas.

to the laboratory for unconfined shear strength determinations.

Descriptions of each of the sampling sites are given in Tables I to 9A.

METHODS

A. Preparation of Samples

Bulk samples were air dried at room temperature. Larger rocks were manually separated and the remaining bulk samples were disaggregated in a steel-roller mill and separated from coarse materials by passing the samples through a 2 mm. sieve.

The Hubalta, Breton, Cooking Lake and Lobley representative till samples were selected as typifying the modal concept of the till groups. The random till samples from the Chip Lake map and adjacent areas, were selected from well drained topographic positions which were considered to be representative of the till map unit.

B. Physical Analyses

(a) Mechanical Analysis: Mechanical analysis of the soil samples was determined by the pipette method described by Toogood and Peters (1953). Salts were removed from the soil by repeated washing; organic matter was removed with H_2O_2; and calcium carbonate was removed with 0.1 N HCl. The content of the fine clay fraction was determined by evaporating an aliquot separated from the total clay fraction by centrifugation as outlined by Baver (1959). The oven dried total sand fraction was placed on a nest of 8 inch sieves of appropriate sizes in order to separate the sands into various sand sizes. The sieves were placed on a "ro-tap shaker" for a period of 30 minutes. The sands retained on the various sieves were weighed and the percentages calculated on a total sand basis. The percentages of sand, silt and clay fractions are

TABLE 1 - Description of Cooking Lake Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
NE 36-52-22-W4	1	35	120	>20	2.5Y 6/4	2.5Y 4/4	L-CL	prismatic, pseudo fine blocky; firm
SW 6-55-19-W4	2	36	65	>20	2.5Y 6/4	2.5Y 4/4	L-CL	laminar, pseudo fine sub-angular blocky; firm
NW 36-52-22-W4	3	37	55	>15	10YR 5/4	10YR 4/2	L-CL	prismatic, pseudo fine blocky; firm
SE 36-51-20-W4	4	36	55	>25	10YR 6/3	10YR 4/2	CL	prismatic, coarse-medium sub-angular blocky; firm
NE 32-51-21-W4	5	35	76	>25	10YR 6/3	10YR 4/4	CL	prismatic, pseudo coarse blocky; very firm

Bedrock-- no bedrock in the vicinity of the sampling sites.

Comments-- iron concretions and iron stains are common.

* Munsell colors

TABLE 1A - Description of Topography and Land Form at the Cooking Lake Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography
1	2400	at crown of hump	hummocky dead ice moraine	rolling with complex slope of about 12 per cent; humpy
2	2400	at crown of hump	hummocky dead ice moraine	rolling to gently rolling with complex slope of about 8-10 per cent; humpy
3	2400	at crown of hump	hummocky dead ice moraine	gently rolling with complex slope of about 7 per cent; humpy
4	2500	at crown of hump	hummocky dead ice moraine	rolling to gently rolling with complex slope of about 10 per cent; humpy
5	2400	at crown of hump	hummocky dead ice moraine	rolling with complex slope of about 15 per cent; humpy

* Above sea level

TABLE 2 - Description of Breton Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
SE 3-48-3-W5	6	60	70	8	2.5Y 6/2	10YR 4/4	L-CL	pseudo fine sub-angular blocky; firm
SW 36-47-2-W5	7	60	65	7	2.5Y 6/2	5Y 5/4	L	massive to fine sub-angular blocky; friable
SE 30-50-7-W5	8	61	72	9	2.5Y 6/2	2.5Y 5/4	L-CL	massive to pseudo fine sub-angular blocky; firm
NE 33-47-27-W4	9	60	70	8	5Y 6/3	2.5Y 5/4	L	fragmental; friable
SE 17-46-2-W5	10	56	86	12	2.5Y 6/3	2.5Y 4/4	L-CL	fragmental to medium sub-angular blocky; firm

Bedrock-- Paskapoo sandstone is found below all sampling sites.

Comments-- olive shale chips, yellow sandstone chips and coal flakes are common.

* Munsell colors

TABLE 2A - Description of Topography and Land Form at the Breton Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography
6	2850	at crown of hump	ground moraine	gently rolling with complex slope to the east of 6 per cent; humpy
7	2900	at crown of hump	ground moraine	gently rolling to rolling with complex slope to the east and west of 10 per cent; humpy
8	2800	200 yards from top of slope	ground moraine	rolling with simple slope to the west-southwest of about 12 per cent
9	2700	20 yards from top of slope	ground moraine	hilly with simple slope to the east-southeast of 28 per cent; creek at bottom of slope
10	2950	at crown of hump	ground moraine	gently rolling to rolling with complex slope of about 8-10 per cent; humpy

* Above sea level

TABLE 3 - Description of Lobley Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
SE 30-34-5-W5	11	44	60	>15	5Y 6/3	2.5Y 5/4	SiCL	massive to pseudo fine-med. sub-angular blocky; friable
SW 27-40-10-W5	12	30	96	>15	5Y 6/3	2.5Y 4/4	CL	laminar, fine sub-angular blocky; firm
NE 34-37-8-W5	13	30	65	>20	5Y 6/3	2.5Y 5/4	SiL	fragmental; friable
NW 30-33-5-W5	14	32	90	>25	5Y 6/3	2.5Y 5/4	CL	pseudo medium sub-angular blocky; firm
NW 7-33-5-W5	15	24	120	>25	5Y 6/4	2.5Y 5/4	CL	fine sub-angular blocky; firm

Bedrock-- there are sandstone outcrops in the vicinity of the sampling sites.

Comments-- sandstone bedrock fragments are incorporated in the till; large Paskapoo sandstone slabs are common; till is generally stony.

* Munsell colors

TABLE 3A - Description of Topography and Land Form at the Lobley Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography
11	3600	at crown of hump	hummocky dead ice moraine	rolling with complex slope of about 15 per cent; humpy
12	3500	near bottom of slope	ground moraine	gently rolling with simple slope to the south of 9 per cent
13	3600	at crown of hump	ground moraine	gently rolling to rolling with complex slope of about 9 per cent; humpy
14	3800	approximately 25 yards from top of slope	ground moraine	rolling with simple slope to the south of 12 per cent
15	3800	at crown of slope	ground moraine	hilly with simple slope to the south of 20 per cent

* Above sea level

TABLE 4 - Description of Hubalta Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
SE 27-55-14-W5	16	48	72	10	2.5Y 6/2	2.5Y 4/4	CL	pseudo medium-fine sub-angular blocky; friable
NE 32-52-13-W5	17	38	44	>10	2.5Y 7/2	2.5Y 4/3	CL	pseudo medium-fine sub-angular blocky; friable
NW 9- 52-10-W5	18	38	48	>12	10YR 5/3	2.5Y 4/4	CL	pseudo fine sub-angular blocky; firm
SE 24-48-6-W5	19	66	73	>10	5Y 5/3	2.5Y 4/4	CL	pseudo fine sub-angular blocky; firm
SW 18-50-11-W5	20	45	50	>10	2.5Y 5/2	2.5Y 4/4	CL	fragmental; firm
SW 6-51-8-W5	21	72	80	> 7	2.5Y 6/2	2.5Y 4/4	CL	fragmental; friable
SW 26-51-13-W5	22	52	65	>15	2.5Y 5/2	2.5Y 4/3	CL	fragmental; firm-friable

Bedrock-- Paskapoo sandstone is the only type seen throughout the sampling area.

Comments-- till is generally stone poor; contains olive shale chips and coal fragments.

* Munsell colors

TABLE 4A - Description of Topography and Land Form at the Hubalta Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography
16	2850	7 yards from top of slope	ground moraine	gently rolling with simple slope to the north-northeast of 8 per cent
17	3000	at crown of hump	ground moraine	rolling with complex slope of about 15 per cent; humpy
18	2900	at crown of low hump	ground moraine	undulating to gently rolling with complex slope to the south of 3 per cent
19	2750	at crown of hump	ground moraine	gently rolling with complex slope of about 5 per cent; humpy
20	3150	at crown of hump	ground moraine	gently rolling with complex slope to the west of 8 per cent; humpy
21	2900	midway down slope	ground moraine	undulating to gently rolling with simple slope to the west of 3 per cent
22	3400	on side of hump	hummocky dead ice moraine	rolling with complex slope of 10 per cent; humpy

* Above sea level

TABLE 5 - Description of Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
SE 33-57-10-W5	23	52	63	>20	2.5Y 5/2	2.5Y 4/4	CL	laminar, pseudo medium-coarse sub-angular blocky; firm to friable
SE 2-57-12-W5	24	59	63	>7	10YR 6/3	2.5Y 4/4	CL	pseudo medium-coarse sub-angular blocky; firm to friable
SW 30-57-13-W5	25	48	72	8	2.5Y 5/2	2.5Y 4/4	CL	pseudo fine sub-angular blocky: firm
NE 30-53-10-W5	26	45	72	>6	2.5Y 5/2	2.5Y 4/4	CL	pseudo fine sub-angular blocky to massive; friable
SW 1-55-9-W5	27	48	60	>7	2.5Y 6/2	2.5Y 4/4	CL	pseudo medium sub-angular blocky to massive; friable

* Munsell colors

TABLE 5A - Description of Topography and Land Form at the Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography	Comments and Tentative Name of Till
23	2850	at crown of hump	ground moraine	rolling with complex slope of about 15 per cent; humpy	no bedrock outcrops in the vicinity; till has a lot of iron concretions: Hubalta or Cooking Lake till
24	3000	near top of slope	ground moraine	rolling with simple slope to the west-southwest of 15 per cent	no bedrock outcrops in the vicinity; till is iron stained: Hubalta till
25	2900	at crown of hump	ground moraine	rolling with complex slope to the east of 12 per cent; humpy	green Paskapoo shale below the till at site; olive shale, sandstone fragments, and coal chips are common: Hubalta till
26	2650	at crown of slope	ground moraine	gently rolling with simple slope to the north of 3 per cent	no bedrock outcrops in the vicinity: Hubalta till
27	2750	at crown of hump on crown of slope	ground moraine	gently rolling with complex slope to the south-west of 4 per cent	no bedrock outcrops in the vicinity but is a lot of sandstone incorporated into the till: Hubalta till

* Above sea level

TABLE 6 - Description of Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
SE 7-55-11-W5	28	48	66	>6	2.5Y 5/2	2.5Y 4/4	CL	pseudo fine to medium sub-angular blocky to massive; friable
NW 36-52-8-W5	29	42	50	>5	2.5Y 6/2	2.5Y 4/4	CL	massive to pseudo fine sub-angular blocky; friable
NE 33-54-8-W5	30	55	72	>9	2.5Y 6/2	2.5Y 4/4	CL	pseudo medium sub-angular blocky to massive; friable to firm
SE 33-55-9-W5	31	40	55	>10	5Y 6/3	2.5Y 4/4	CL	massive to pseudo medium sub-angular blocky; friable to firm
SW 29-56-10-W5	32	45	53	>7	2.5Y 6/2	5Y 5/4	L-CL	pseudo fine sub-angular blocky to massive; friable

* Munsell colors

TABLE 6A - Description of Topography and Land Form at the Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography	Comments and Tentative Name of Till
28	2700	midway up slope	ground moraine	undulating to gently rolling with simple slope to the west of 2-3 per cent	Paskapoo sandstone bedrock outcrop 2 miles to the north-east; till has a lot of sand-stone, olive shale chips, and coal flakes incorp. in it: Hubalta and/or Breton till
29	2700	midway up slope	ground moraine	undulating with simple slope to the east of 1 per cent	no bedrock outcrops in the vicinity; lacustrine approx. 500 yards to the east: Breton and/or Cooking Lake till
30	2750	at crown of hump	ground moraine	gently rolling with complex slope of 8-9 per cent; humpy	no bedrock outcrops in the vicinity; olive shale, sand-stone fragments, and coal chips are common: Hubalta and/or Cooking Lake till
31	2700	at crown of hump	ground moraine	gently rolling to rolling with complex slope to the south of about 10 per cent; humpy	no bedrock outcrops in the vicinity; till is dense and contains olive shale chips and sandstone fragments: Hubalta till
32	2600	midway down side of slope	ground moraine	gently rolling with simple slope to the northwest of 4 per cent	Paskapoo sandstone exposed 4 miles to the west: Hubalta and/or Breton till

* Above sea level

TABLE 7 - Description of Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
NE 36-57-8-W5	33	40	65	>20	2.5Y 6/2	2.5Y 4/4	L-CL	pseudo fine sub-angular blocky to massive; friable
SE 6-54-13-W5	34	48	55	> 6	2.5Y 6/2	2.5Y 4/4	CL	pseudo fine to medium sub-angular blocky; firm
SW 19-46-3-W5	35	60	72	>10	5Y 6/4	2.5Y 4/4	CL	massive to pseudo fine sub-angular blocky; friable
SW 21-51-11-W5	36	53	65	> 8	2.5Y 6/2	2.5Y 4/4	CL	massive to pseudo fine sub-angular blocky; firm
SE 4-51-10-W5	37	40	70	>7	2.5Y 5/2	2.5Y 4/4	Cl	pseudo medium sub-angular blocky to massive; firm

* Munsell colors

TABLE 7A - Description of Topography and Land Form at the Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography	Comments and Tentative Name of Till
33	2300	midway down side of hump	ground moraine	rolling with complex slope to the east of 15 per cent; humpy	no bedrock outcrops in the vicinity; numerous sand lenses and sand pockets in the till: Cooking Lake till
34	2800	at crown of hump	ground moraine	gently rolling with complex slope to the southeast of 5 per cent; humpy	no bedrock outcrops in the vicinity; sandstone fragments, olive shale chips and coal flakes are common: Hubalta till
35	2900	at crown of hump	ground moraine	rolling with complex slope of 12 per cent; regional slope to the south of 4 per cent; humpy	green Paskapoo shale outcrops 1 mile to the north; sandstone fragments, olive shale chips and coal flakes are common: Breton and/or Hubalta till
36	3100	at crown of hump, midway down regional slope	ground moraine	gently rolling with complex slope of 8 per cent; regional slope to the south of 3 per cent; humpy	Paskapoo sandstone outcrops 2 miles to the southeast: Hubalta till
37	2900	at crown of hump	ground moraine	gently rolling to rolling with complex slope of about 9 per cent; humpy	Paskapoo sandstone outcrops approximately 175 yards to the south: Breton and/or Hubalta till

* Above sea level

TABLE 8 - Description of Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
SW 27-49-11-W5	38	48	60	>7	2.5Y 6/2	2.5Y 5/4	CL	fragmental; friable
NW 35-49-9-W5	39	58	80	8	2.5Y 7/2	2.5Y 5/4	CL	massive; firm
SE 6-50-7-W5	40	44	55	> 8	10YR 6/3	10YR 4/4	L-CL	fragmental; firm
NE 13-50-13-W5	41	>84	84	10	2.5Y 5/4	2.5Y 4/4	CL	pseudo fine sub-angular blocky to fragmental; firm
NW 26-49-13-W5	42	>72	72	> 7	2.5Y 5/4	2.5Y 4/4	CL	massive; firm

* Munsell colors

TABLE 8A - Description of Topography and Land Form at the Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography	Comments and Tentative Name of Till
38	3100	on side of borrow pit	ground moraine	undulating with simple slope to the north of 1 per cent	no bedrock outcrops in the vicinity; till is relatively stone poor; sandstone fragments,olive shale chips and coal flakes are common: Hubalta till
39	2900	near crown of slope	ground moraine	gently rolling with simple slope to the east of 4 per cent	Paskapoo sandstone exposed 1 mile to the east on the Pembina river; olive shale chips, sandstone fragments, and coal chips are common: Hubalta and/or Breton till
40	2800	near crown of slope	ground moraine	gently rolling with simple slope to the west of 5 per cent	Paskapoo sandstone outcrops to the northeast; sand pockets, coal, and olive shale chips are common: Hubalta and/or Breton till
41	3100	near crown of slope	ground moraine	rolling with simple slope to the west-southwest of 14 per cent: on bank of creek	Paskapoo sandstone outcrops 35 yards down the slope; sandstone fragments, olive shale chips, and coal flakes are common: Hubalta till

* Above sea level

TABLE 9 - Description of Till Sampling Sites

Legal Location	Sample Number	Depth of Profile (in.)	Depth of Sample (in.)	Depth of Till (ft.)	Color* (Dry)	Color* (Moist)	Texture	Structure and Consistency
NE 21-50-12-W5	43	63	40	7	2.5Y 5/4	2.5Y 3/2	CL	pseudo medium sub-angular blocky to fragmental; very firm
NE 21-50-12-W5	44	63	68	7	10YR 6/3	2.5Y 5/4	L	massive; firm
SW 28-53-18-W5	45	25	72	>10	5Y 6/3	5Y 5/4	L-SL	massive to pseudo fine sub-angular blocky; friable
NE 21-50-24-W5	46	32	84	10	2.5Y 6/2	10YR 5/4	SiCL	massive; friable

* Munsell colors

TABLE 9A - Description of Topography and Land Form at the Till Sampling Sites

Sample Number	Elevation* (ft.)	Sample Position	Land Form	Topography	Comments and Tentative Name of Till
42	3200	near crown of slope	ground moraine	undulating to gently rolling with simple slope to the north-northeast of 3 per cent	no bedrock outcrops in the vicinity; till seems to be darker, finer textured and more massive than previous samples: Hubalta till
43	3150	at crown of hump	ground moraine	undulating with complex slope to the west of 2 per cent; humpy	Paskapoo sandstone bedrock at site; till is dark and compact; no coal, shale,or sandstone fragments observed: Hubalta till
44	3150	at crown of hump	ground moraine	undulating with complex slope to the west of 2 per cent; humpy	Paskapoo sandstone bedrock at site; contains a lot of coal and sandstone fragments; olive shale chips are absent: Breton till
45	3200	at crown of hump and slope	ground moraine	gently rolling to rolling with complex slope to the west of about 15 per cent; humpy	no bedrock outcrops in the vicinity but Paskapoo sand-stone and shale fragments are common; till is fairly stony: Lobley till
46	4200	on side of drumlin	drumlinized ground moraine	hilly with complex slope of about 30 per cent	a lot of sandstone is incorp. in the till: Unknown till

* Above sea level

based on oven-dry weight of organic matter-free, salt-free and carbonate-free soil material.

(b) Bulk Density and Penetrometer readings: Bulk density was determined on core samples collected with a "Uhland Core Sampler". The samples were oven dried, weighed, and the bulk density calculated. Penetrometer values were determined in the field by ejecting a pocket penetrometer into fresh exposures of the till at each of the sampling sites. The average value for 25 penetrometer readings was used to determine the degree of compactness of the till and is reported for each sampling site.

(c) Real Specific Gravity: The pycnometer bottle method cited in Lyon and Buckman (1922) was used for real specific gravity analysis. Distilled water was used as the liquid medium.

(d) Distribution of Coarse Fragments: The bulk samples containing rock fragments larger than 2 mm. in diameter were separated into six grade sizes, with the lower limit of the sizes at 4mm., 8mm., 16mm., 32mm., 64mm., and 128mm., respectively, according to a modified Wentworth (1922) classification. The grade sizes were used without regard to particle shape. The rock fragments were separated with the aid of a simple measuring device consisting of a sheet of metal containing holes of diameter equivalent to the previously mentioned sizes. Percentage by number rather than by weight was used in the grade size analysis of the coarse fraction.

(e) Pebble Count: At each sampling site approximately 350 pebbles were picked from freshly exposed till. The pebbles were selected from a predetermined area of approximately 10 sq. ft., and generally consisted of pebbles larger than 10 mm. in size. These were differentiated into the following categories:

Limestones
Dolomites
Granites
Sandstones
Quartzites
Others

A magnifier, dilute HCl, and a pen knife were used as an aid in identification. All calculations were based on a number percentage.

(f) Micro-fabric Investigations: Uhland core samples, from selected representative till sites, with natural orientation maintained, were used for micro-fabric investigations. The method used for impregnation was that of Acton (1961) as modified by Dumanski (1964). The impregnating media consisted of Castolite-X, thinner and hardner. Interference colors produced by quartz grains were used as a guide in thickness estimation, during slide preparation. A petrographic microscope was utilized in examining and describing the prepared thin sections.

(g) Unconfined Shear tests: The unconfined shear tests were determined using the procedure of Lambe (1951). This essentially involves placing a 4 to 7 inch Shelby core sample in the unconfined compression apparatus and compressing the sample until failure occurs. Readings on the proving ring dial and vertical deflection dial were obtained every 30 seconds. The unconfined compression machine used was a "Soil Test Model, U-120".

C. Chemical Analyses

(a) Soil Reaction: pH was determined on a water saturated soil paste as outlined by Doughty (1941), using a Beckman model zeromatic pH meter equipped with a glass and calomel electrode.

(b) Calcium Carbonate Equivalent: A modification of the procedure described in A.O.A.C. methods of analysis (1955) was used to determine

carbonate carbon. The CO_2 evolved by treating the sample with H_2SO_4 and $FeSO_4$ was absorbed in ascarite and determined gravimetrically.

(c) Cation Exchange Capacity: Exchangeable cations were extracted from the sample with 1 N. NH_4OAc adjusted to pH 7 as outlined in the A.O.A.C. methods of analysis (1955). The cation exchange capacity was determined by extraction of adsorbed ammonium with 1 N NaCl and distillation of the extract was carried out according to the method outlined in A.O.A.C. (1955).

(d) Extractable Iron and Aluminum: The citrate-dithionate extraction method outlined by Jackson (1956) was used for removal of iron and aluminum oxides. Iron and aluminum, in the extracts, were determined colorimetrically using O-phenanthroline and "aluminon" respectively, for color development, as described by Olson (1965).

(e) Electrical Conductivity of Saturation Extracts: A saturated soil paste was prepared according to the procedure outlined in U.S.D.A. Handbook 60 (1954). The saturation extract was obtained by suction, and the conductivity of the extract was measured with a direct reading Solu-Bridge Model RD-26.

(f) Soluble Salts: The soluble cations measured in the saturation extract were Na^+, Ca^{++}, K^+, and Mg^{++}. All soluble cations were determined with the Perkin Elmer model 303 Atomic Absorption Spectrophotometer.

D. Mineralogical Analyses

1. Clay Analyses

(a) Preparation of Clay Samples: Separation of the total clay fraction (less than 2 microns) from the samples was achieved by gravity sedimentation as outlined by Jackson (1949) and modified by Pawluk (1961). The initial treatment prior to segregation of the clay fraction consisted

of removing carbonates, soluble salts and organic matter from the samples. The clays were dispersed by adjusting the soil suspension to pH 8.0 with NaOH. The suspension was allowed to equilibrate overnight and then readjusted to pH 8.0. The separation of the clay was accomplished by repeated decantation of the upper 8 cm. of suspension after standing for 6 hours and 8 minutes as determined from Stoke's Law (Baver, 1959). The clay fraction was flocculated with $CaCl_2$ followed by washing with distilled water and ethanol to remove chlorides. The total clay fraction was then dried at 60°C, ground to pass a 200 mesh sieve and stored in vials.

(b) X-ray Analysis of Clay Minerals: The clay samples were prepared for x-ray analysis according to the method of Kittrick (1961). Essentially this entailed taking a few drops of clay suspension, placing it on a glass slide and allowing the suspension to dry. The clay samples were glycolated by placing the prepared slides in a saturated atmosphere of ethylene glycol in an oven set at 60°C for 48 hours. Dehydration was accomplished by heating the slides to 550°C for two hours.

A Philips x-ray diffractometer equipped with a high angle goniometer, CuKα radiation, and a nickel filter was used to identify the clays. The x-ray unit was set at 40 kilovolts, 20 milliamperes with a scanning time of one degree 2θ per minute. Slit sizes used were 1°, .1 mm., and 1° with chart speed set at 1 cm. per minute.

(c) Differential Thermal Analysis: An Aminco Thermal Analyzer, model 4-4442, was used for differential thermal analysis of clays. The samples were firmly packed into the sample holder and pure γ-alumina was used as a reference material. Samples were heated at a constant

rate of 16°C. per minute. Thermocouple sensitivity was maintained at a setting of 0.5°C. per inch differential and recorder sensitivity was set at 5 millivolts per division for the X axis and 0.5 millivolt per division for the Y axis.

(d) Surface Area: Total surface areas were determined on the clays, using the method outlined by Heilman et al (1965). The samples were saturated with ethylene glycol monoethyl ether and placed in a vacuum oven. A beaker containing $CaCl_2$ plus ethylene glycol monoethyl ether was placed in the oven along with the samples. A vacuum of 27 p.s.i. was applied for a period of three hours and weighed. The vacuum treatment was continued until the samples reached a constant weight between two consecutive half hour intervals. Standard calcium saturated Arizona montmorillonite was used as an internal standard and was considered to have a surface area equal to 980 $m.^2/g.$.

(e) Clay Fusion and K_2O Content: One gram of clay from each sample was heated in a muffle furnace to 850°C. The clay was then treated with two 10 ml. volumes of HCl and HF (conc.) with intermittent evaporation to near dryness. After the second HCl and HF treatments, the residue was heated to dryness, treated with 5 ml. of HCl and again heated to dryness. The residue was taken up in 5 per cent HCl and made to volume. Potassium concentration was determined with the Perkin Elmer model 303 Atomic Absorption unit.

(f) Cation Exchange Capacity of Total Clay: One gram samples were treated with 3 successive portions (40 ml.) of 1 N. NH_4OAc, using 4 hour shaking intervals, except for the last treatment when the mixture was shaken for 12 hours. Excess NH_4OAc was washed free from the clay with a water and alcohol solution using the centrifuge. The adsorbed NH_4 was

extracted with 3 treatments of 1 N. NaCl. The content of replaced NH_4 was determined by distillation as outlined in A.O.A.C. (1955).

2. Sand Analyses

(a) Preparation of Sand Samples: The sand and silt fractions which were separated from the clay fraction, were further subdivided by wet sieving with the aid of a 300 mesh sieve. The sand fraction remaining on the sieve was thoroughly washed and fractionated with the aid of a "ro-tap shaker". Sieving was conducted for 30 minutes. The fine sand fraction (0.114mm.-0.25mm.) was thoroughly cleaned by boiling the sand particles in a dilute HCl acid-water mixture for 30 minutes. The fine sand fraction was retained in vials for further analyses.

(b) Light and Heavy Mineral Separations: The light and heavy mineral fraction of the fine sand fraction (0.114mm.-0.25mm.) was obtained by heavy liquid separation. The heavy liquid used was tetrabromoethane with specific gravity of 2.96. A weight percentage of the light and heavy minerals was determined.

(c) Light Mineral Analysis (SG. $<$ 2.96): Chemical composition of the light mineral fraction was determined by the HCl and HF method as outlined by Pawluk (1967). Elemental analysis was determined for Ca^{++}, K^{+}, and Na^{+} on the decomposed samples with the Perkin Elmer model 303 Atomic Absorption unit.

(d) Heavy Mineral Analysis (SG. $>$2.96): The heavy mineral grains from the 22 representative till samples were mounted in Aroclore No. 4465 (n=1.664 to 1.667) and the percentages of the different mineral species were determined by identifying at least 300 grains from each slide using a petrographic microscope.

E. Computer Analyses

An I.B.M. 360/67 computer located at the Computer Centre, University of Alberta was used to conduct statistical analysis. Analysis of variance and Duncan's new multiple range test were carried out on 40 of the 46 till samples obtained for the study. The computer program used, is cited in Appendix A (Figure Ic).

On the basis of field characteristics 22 samples were collected to represent the 4 tills under study. The statistical limits of 58 independent variables were established for the 4 groups of samples.

The remaining 18 samples were collected in the Chip Lake map area, where the field mapping program was underway. On the basis of field characteristics the 18 samples were placed into 2 groups, one of which was thought to be reasonably similar to the Hubalta till (11 samples) and the other a Hubalta - Breton till intergrade (7 samples). The degree of similarity was evaluated with the aid of a computer. The remaining 6 samples could not be categorized with the computer because of wide discrepancies in their field characteristics. These samples were handled on an individual basis.

IV. RESULTS AND DISCUSSION

For purposes of discussion the results are shown in two parts; Part A and Part B. Part A refers exclusively to the 4 reference till groups, Hubalta, Breton, Cooking Lake and Lobley. Part B refers to a number of random samples obtained in the Chip Lake map and adjacent areas in west-central Alberta. In this section an attempt is made to relate the samples to at least one of the above mentioned reference till groups.

Part A - Reference Till Samples

Physical, chemical, mineralogical and micropedological analyses were conducted on till samples collected in west-central Alberta in order to characterize the Lobley, Breton, Hubalta and Cooking Lake glacial till parent materials. The statistical results of some of these analyses appear in Tables 10 to 20. The individual sample results comprising the 4 groups of till are shown in Appendix A, Tables Ic to XIc.

The tables of data for various statistical analyses are comprised of 2 parts. The first part reports the mean and standard deviation for the 4 groups of till. The second part indicates significant differences between different groups of till, in decreasing order of significance, as determined by "Duncan's" new multiple range test for the various analyses. The range test was carried out at 95 per cent confidence limits and thus an F value of greater than 3.160 was required for all analyses, except the heavy mineral analyses, in order for significant differences to occur. The heavy mineral analysis was

conducted on 23 samples instead of 22, as was the case for the remaining analyses. A higher number of degrees of freedom bestows an F value of 3.130 at the 95 per cent level of significance. The F values shown at the bottom of the tables suggests the degree of difference among the 4 tills. Large F values reflect a greater range of differences among the 4 tills than small F values. Any F value smaller than 3.160 (3.130 for the heavy mineral analysis) indicates no significant difference among the 4 tills at the 95 per cent level. All statistical analyses on the data were conducted with the aid of a computer.

Physical Analyses

Particle Size Analysis: Mechanical analysis provides the percentage distribution of particle sizes in a soil sample (Baver, 1959). The size separations are those used by the U.S.D.A. (Soil Survey Staff, 1951). The statistical results of the 4 groups of till are reported in Tables 10 and 11. The individual sample results are reported in Appendix A, Table Ic. Figure 4 illustrates the means and standard deviations of the 4 groups of till for the various sand separates.

The 4 tills studied are of a loam to clay loam texture.

The Cooking Lake till contains a significantly higher percentage of sand than the 3 remaining tills. Only the Hubalta and Lobley tills do not have significantly different amounts of sand. The fine and very fine sand fractions generally comprise 75 per cent of the total sand in the Hubalta, Breton and Lobley tills while the Cooking Lake till contains a significantly lower percentage. The lower content of very fine sand and fine sand in the Cooking Lake till is reflected by a corresponding increase in the very coarse and coarse

TABLE 10 - Statistical Analyses for Sand, Silt, Clay, and Fine Clay Particle Size Distribution of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	Sand (%)	Silt (%)	Clay (%)	Fine Clay (%)
Cooking Lake Till 1-5	5	42.2±2.6	34.4±1.5	23.4±2.3	11.8±1.8
Breton Till 6-10	5	37.6±2.3	39.0±1.6	23.4±2.2	10.0±1.6
Lobley Till 11-15	5	27.4±4.0	43.6±4.2	29.0±6.4	10.0±2.3
Hubalta Till 16-22	7	30.1±2.0	36.7±3.5	33.1±2.1	16.3±2.8

B. Significant Differences as Determined by Duncan's New Multiple Range Test**

Sand* (%)	Silt* (%)	Clay* (%)	Fine Clay* (%)
Ck.-Lob.	Ck.-Lob.	Hub.-Bn.	Hub.-Bn.
Ck.-Hub.	Lob.-Hub.	Hub.-Ck.	Hub.-Lob.
Bn.-Lob.	Lob.-Bn.	Lob.-Ck.	Hub.-Ck.
Bn.-Hub.	Bn.-Ck.	Lob.-Bn.	
Ck.-Bn.			
F=31.88	F=8.77	F=10.39	F=10.98

Lob. - Lobley Till Group
Bn. - Breton Till Group
Ck. - Cooking Lake Till Group
Hub. - Hubalta Till Group

* Ranked according to decreasing levels of significance

** 95% confidence limits

TABLE 11 - Statistical Analyses for the Sand Separates Distribution of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	V.C.S. (%)	C.S. (%)	M.S. (%)	F.S. (%)	V.F.S. (%)
Cooking Lake Till 1-5	5	5.0±2.1	15.2±3.6	15.9±1.0	37.7±3.0	26.2±3.1
Breton Till 6-10	5	1.9±0.7	8.2±1.1	15.4±1.2	42.3±5.2	32.2±4.9
Lobley Till 11-15	5	4.3±1.4	7.1±1.4	13.2±1.9	38.4±0.5	37.0±2.8
Hubalta Till 16-22	7	1.7±0.8	8.7±2.4	14.9±2.1	43.1±1.4	31.5±4.6

B. Significant Differences as Determined by Duncan's New Multiple Range Test**

V.C.S.* (%)	C.S.* (%)	M.S.* (%)	F.S.* (%)	V.F.S.* (%)
Ck.-Hub.	Ck.-Lob.	No Significant Difference	Hub.-Ck.	Lob.-Ck.
Ck.-Bn.	Ck.-Bn.		Hub.-Lob.	Ck.-Bn.
Lob.-Hub.	Ck.-Hub.		Bn.-Ck.	Ck.-Hub.
Lob.-Bn.			Bn.-Lob.	Hub.-Lob.
F=8.43	F=12.28	F=2.42	F=4.75	F=6.03

V.C.S. - 1.00mm.-2.00mm.
C.S. - 0.50mm.-1.00mm.
M.S. - 0.25mm.-0.50mm.
F.S. - 0.10mm.-0.25mm.
V.F.S. - 0.05mm.-0.10mm.

* Ranked according to decreasing levels of significance
** 95% confidence limits

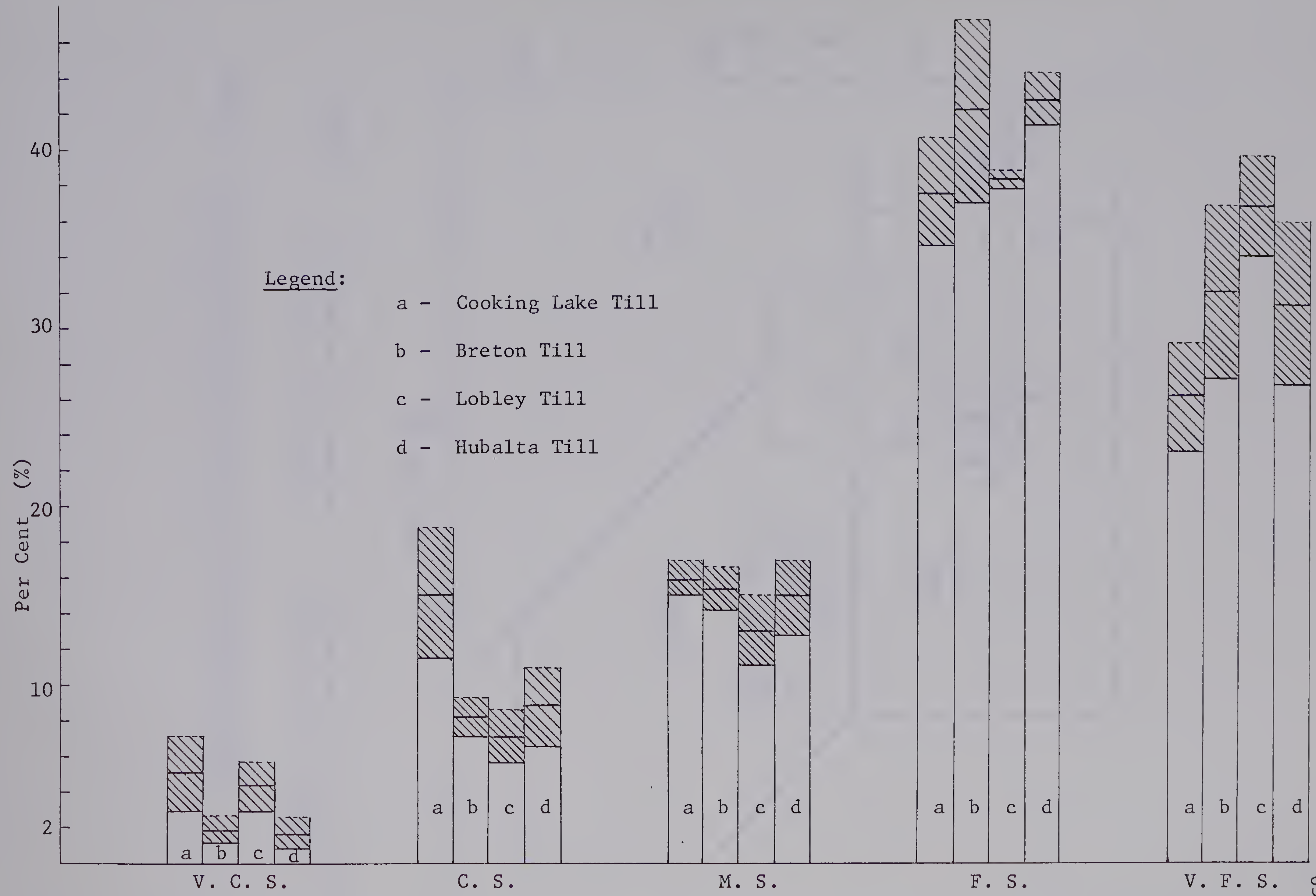
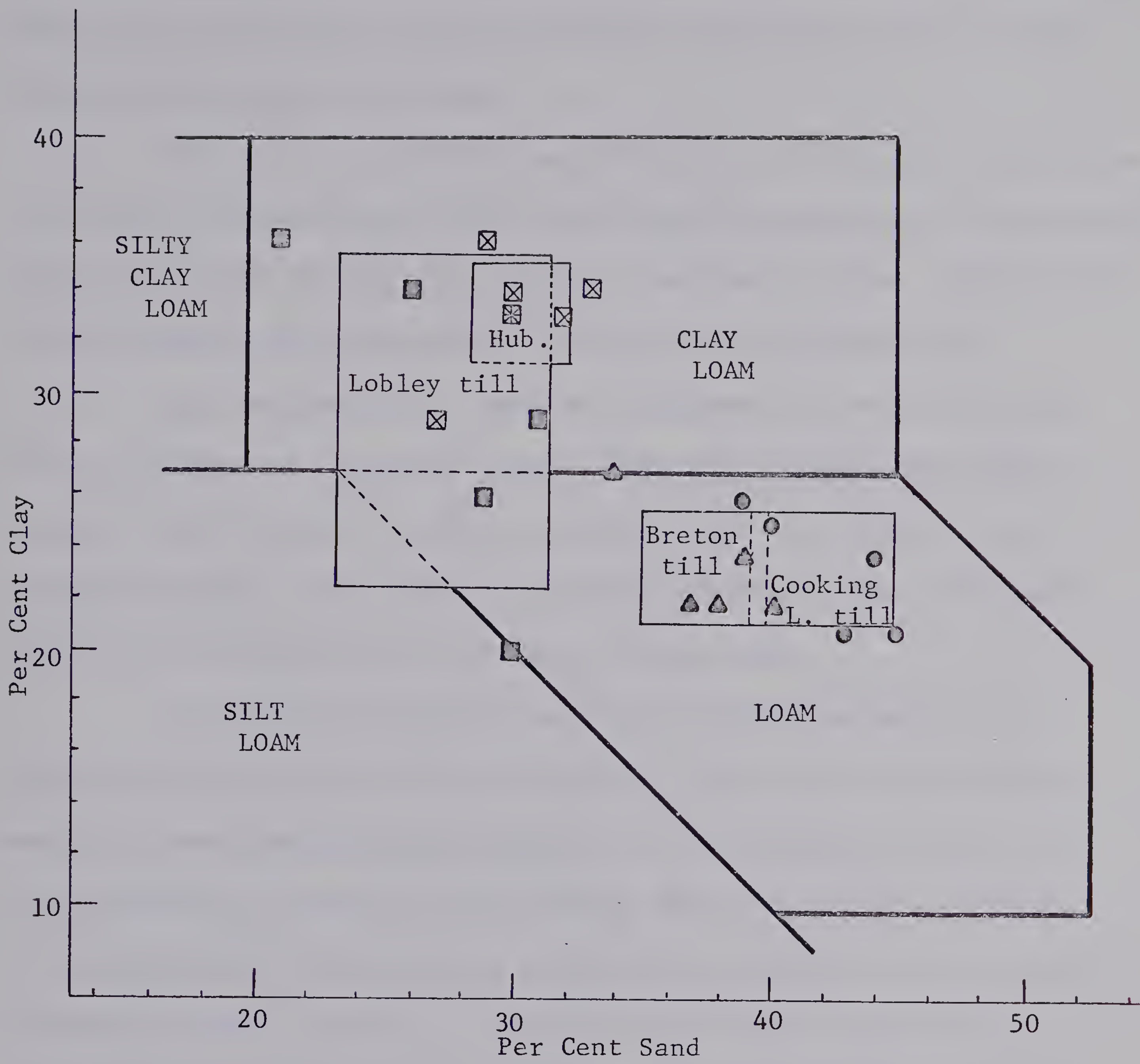


Figure 4 -Histograms Showing the Mean and Standard Deviation for the Sand Separates of the Reference Tills



Legend: ⊠ Hubalta till samples ● Cooking Lake till samples
△ Breton till samples □ Lobley till samples

Figure 5 - Particle Size Distribution of the Reference Tills
(rectangles indicate the standard deviation from the mean)

sand fractions. The Cooking Lake till contains a significantly higher percentage of coarser sand particles than the other 3 tills. There is a great deal of similarity between the Breton and Hubalta tills for the various sand separate fractions.

Generally the Hubalta and Lobley tills are finer textured than the Cooking Lake and Breton tills, with Hubalta containing a significantly higher percentage of fine clay than the remaining 3 tills. On the basis of mechanical analysis data, all 4 tills can be differentiated.

The variability in texture is greatest in the Lobley till. This is illustrated in Figure 5 which shows the minimum and maximum per cent sand and clay, for the 4 groups of till on a portion of a textural triangle. The total clay content for the Lobley till ranges from a low of 20 per cent to a high of 36 per cent.

According to Gravenor and Bayrock (1965) variations in texture is a function of the local bedrock, direction of ice advance, nature of pre-existing glacial deposits as well as mode of deposition. The difference in texture in the Cooking Lake till could conceivably be caused by mode of deposition, since all the samples were taken from a hummocky dead-ice moraine. A significantly higher percentage of total sand and coarse sand in the Cooking Lake till may reflect sand pockets and lenses evident in the till at the time of sampling.

Similar results in mechanical composition of the C horizon of the tills have been reported by Hortie (1952), Pawluk (1961), Lindsay et al (1968), and Peters and Bowser (1960).

Bulk Density: The statistical results for bulk density determinations are given in Table 12 in grams per cubic centimeter. The individual sample values comprising the 4 tills are given in Appendix A, Table IIc. The values range from a minimum of 1.37 g./c.c. (Hubalta till; site 16)

to a maximum of 1.72 g./c.c. (Cooking Lake till; site 5). According to Buckman and Brady (1960) bulk densities can be as high as 1.80 or 2.00 g./c.c.. These workers stated that there was a tendency for bulk density to become greater with depth because of a decrease in organic matter content and greater compaction. They also state that bulk density generally increases with increasing particle size. The Hubalta till which is generally finer textured, than the other tills has the lowest bulk density. The Cooking Lake and Lobley tills have a significantly higher bulk density than Hubalta till. Hortie (1952) reported that the Cooking Lake till is generally more compact than the Breton till. The values reported for the tills are almost identical to bulk density values determined by Alberta Soil Survey for the Hubalta and Cooking Lake tills (Lindsay and Wynnyk, personal communication).

The variability in bulk density within each of the tills is shown in Figure 6. The large variability may be caused by stones being present in the material making good cores difficult to obtain. Characterization of the 4 tills by bulk density is difficult to evaluate because of the large amount of variability within each till ($F = 4.32$) which may or may not be caused by the inherent features of the till.

Penetrometer values: A pocket penetrometer was used to indicate the degree of compactness of the 4 tills under study. The value for each individual sample is given in Appendix A, Table IIc, and is the average of 25 readings. The statistical results for the tills are given in Table 12. The results suggest that the Cooking Lake till is compacted to a greater degree than the Lobley, Hubalta or Breton tills. Hortie (1952) found similar results when studying the Cooking Lake and Breton soils. The Breton till is the most variable of the 4 tills studied as is illustrated in Figure 6.

TABLE 12 - Statistical Analyses for the Distribution of Some Physical Characteristics of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	Bulk Density g./c.c.	Penetrometer values (tons /ft.^{2})	Depth of profile (in.)	R.S.G.***
Cooking Lake Till 1-5	5	1.61±0.10	3.72±0.78	35.8±0.8	2.61±0.02
Breton Till 6-10	5	1.54±0.08	2.62±1.22	59.4±1.9	2.61±0.02
Lobley Till 11-16	5	1.57±0.05	2.32±0.59	32.0±7.3	2.62±0.03
Hubalta Till 17-22	7	1.47±0.06	1.87±0.42	51.3±13.2	2.59±0.02

B. Significant Differences as Determined by Duncan's New Multiple Range Test*

Bulk Density** g./c.c.	Penetrometer** values (tons/ft.^{2})	Depth of** profile (in.)	R.S.G.**
Ck.-Hub.	Ck.-Hub.	Bn.-Lob.	No Significant Difference
Hub.-Lob.	Ck.-Lob.	Bn.-Ck.	
	Ck.-Bn.	Hub.-Lob.	
		Hub.-Ck.	
F=4.32	F=5.72	F=12.06	F=2.09

* 95% confidence limits
** Ranked according to decreasing levels of significance
*** Real Specific Gravity

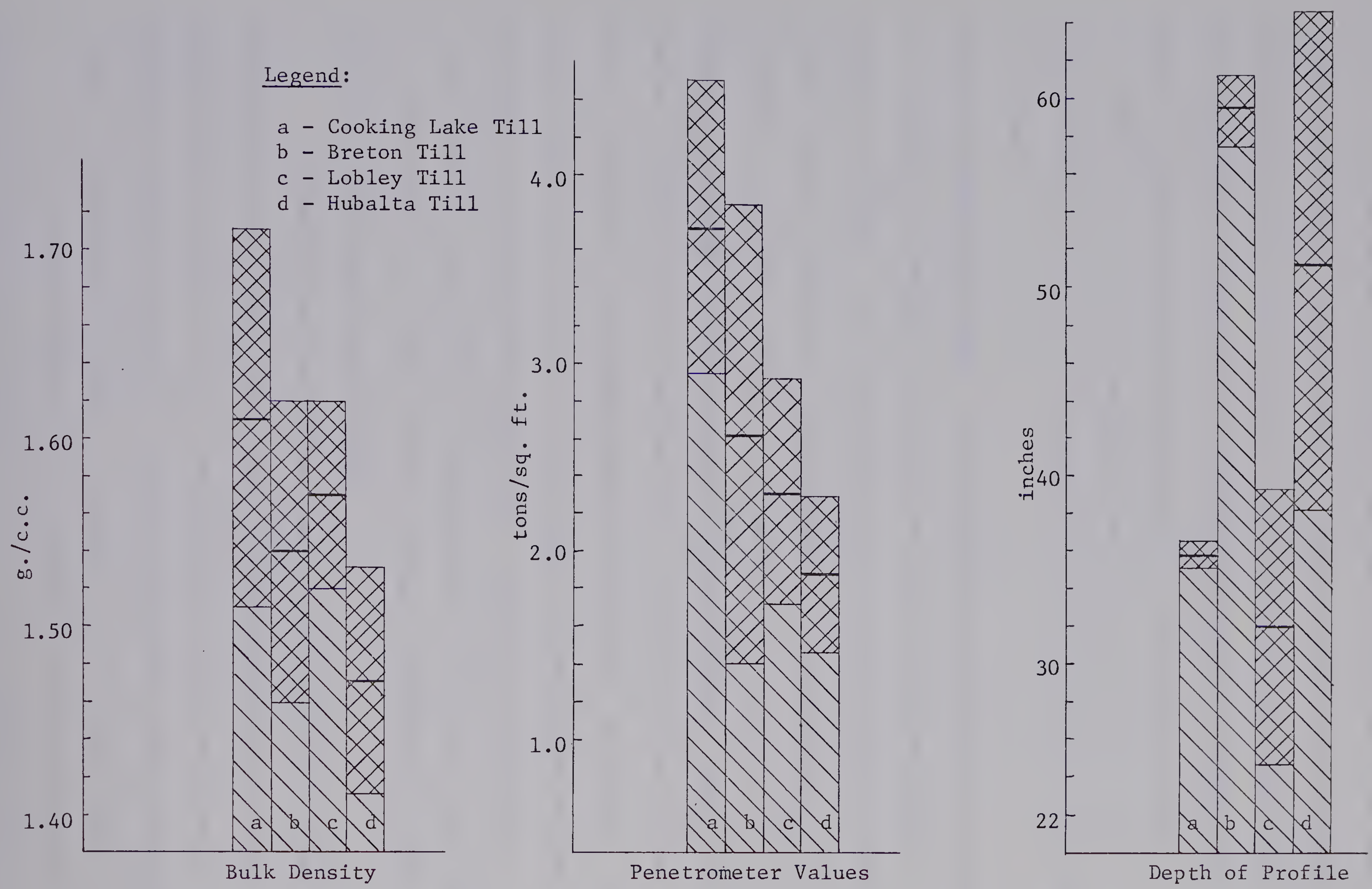


Figure 6 - Histograms Showing the Mean and Standard Deviation for some Physical Characteristics of the Reference Tills

It was noted in the field that the Cooking Lake sites were considerably dryer than other sites. Since the pocket penetrometer does not take into account moisture content it is quite likely that the high values obtained for the Cooking Lake samples is mainly the result of a very low moisture content at the time of the analysis. The difference in moisture content at various sites within a till group probably accounts for the majority of the variability within each till group.

Unconfined Compression tests: The unconfined compression test measures the compressive strength of a cylinder of soil to which no lateral support is offered. It is the simplest and quickest laboratory method commonly used to measure the shear strength of a cohesive soil. The unconfined compression test has an advantage over the direct shear test because of the more uniform stresses and strains imposed (Lambe, 1951). Another advantage of the unconfined test is that the failure surface tends to develop in the weakest portion of the soil. In contrast, the direct shear forces the clay to shear along a predetermined surface, which may or may not be the weakest one. The shape of the stress-strain curve for an unconfined compression test indicates a great deal about the properties of soils and how they may be expected to deform under load (Means and Parcher, 1963).

Unconfined compression tests were carried out on 7 of the representative till sites. The stress-strain relationship is shown graphically in Figures 7 and 8. The tabulated results are shown in Appendix A, Tables IIIc and IVc. Unlike penetrometer values, moisture content at the time of the test, is reported for each core tested.

The results indicate that the Breton till has the highest maximum undisturbed shear strength of the 4 tills studied. Values of

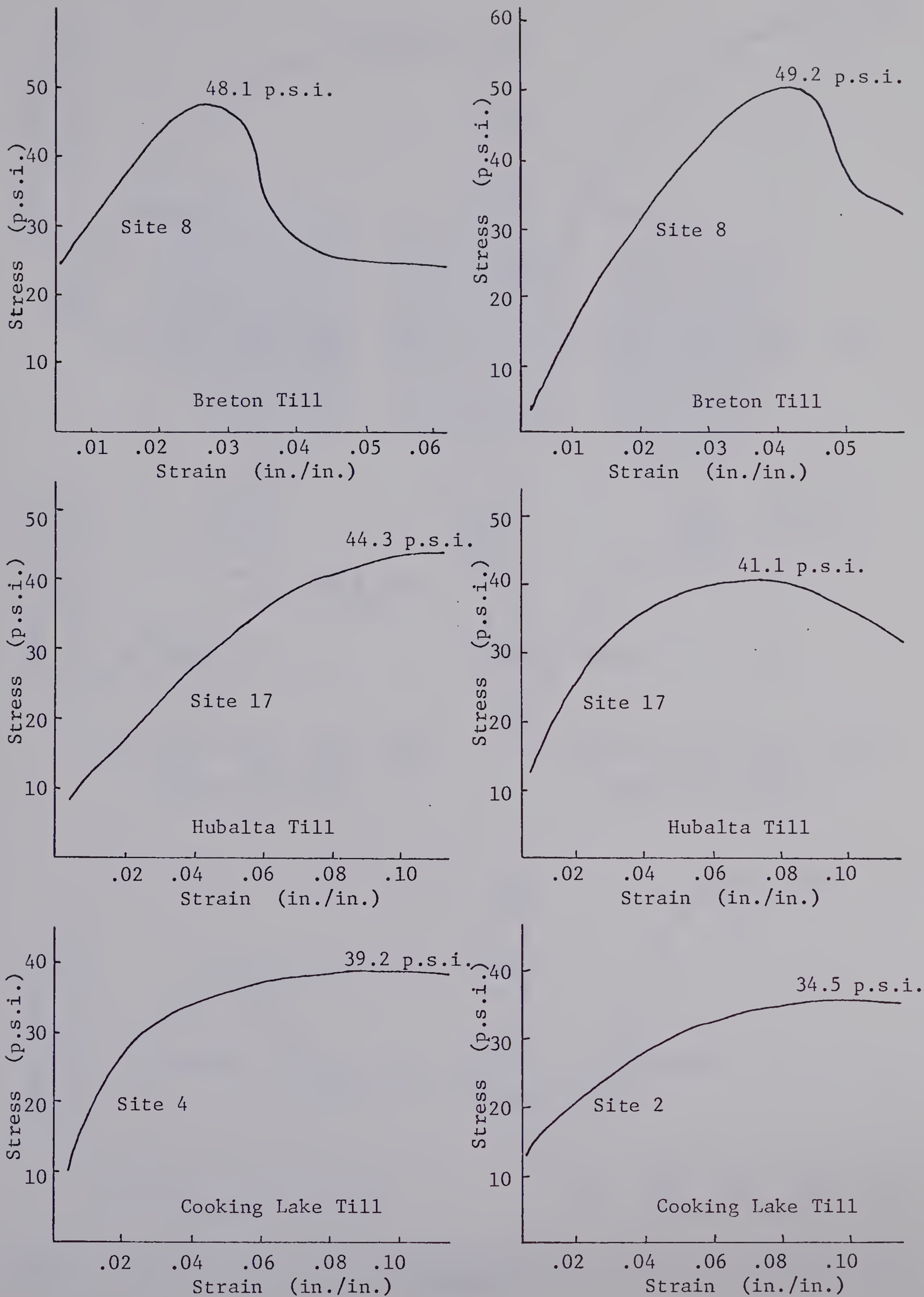


Figure 7 - Stress-Strain Relationship for some of the Reference Till Samples

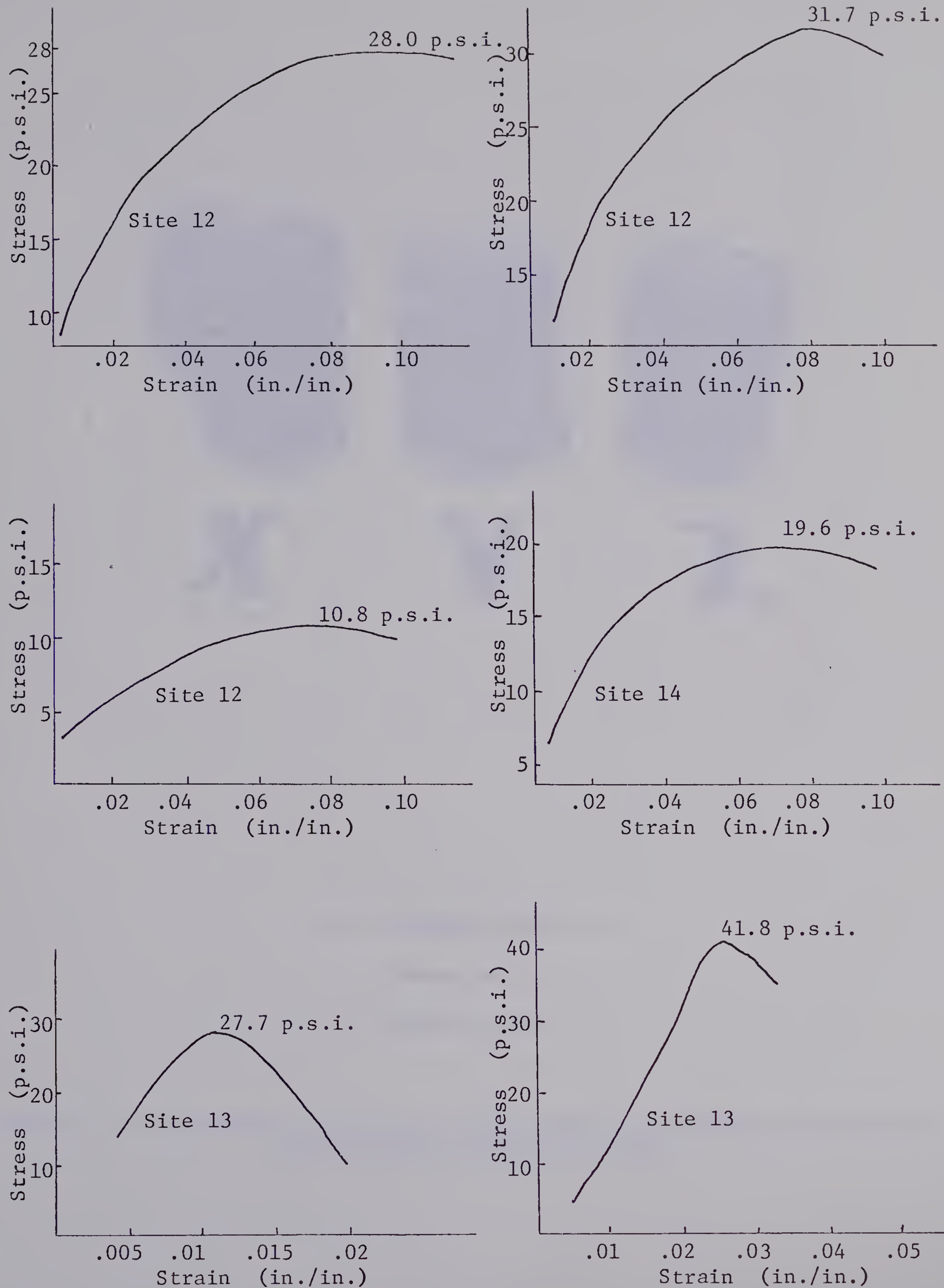


Figure 8 - Stress-Strain Relationship for some of the Lobley Reference Till Samples

X - Cooking Lake core

Y - Breton core

Z - Hubalta core

Plate 1 - Photograph of the Cooking Lake, Breton, and Hubalta cores after the Unconfined Compression Test

48.1 and 49.2 p.s.i. stress are reported for duplicate determinations at site 8. The rapid increase in stress at a relatively low strain suggests that the Breton till is not easily deformed or disturbed by a load. However, when failure occurs, it is rapid, as is illustrated in the stress-strain curves for Breton till, by the rapid fall in stress with increased strain. The levelling off of the stress-strain curve at a lower stress may be due to the binding action of sand particles in a shear plane thus preventing complete failure.

The maximum undisturbed shear strength is slightly higher in the Hubalta till than the Cooking Lake till. Stress-strain curves for the Hubalta and Cooking Lake tills are somewhat similar to the Breton curves under low strain, having characteristic rapid increases in stress. However failure is not as sharp, and the curves take on a flattened appearance with maximum undisturbed shear strength occurring over a wide range of strain. After failure, the stress-strain curves for Cooking Lake and Hubalta indicate that increased strain decreases stress very little. Plate 1 illustrates the Hubalta, Breton and Cooking Lake cores after the compression tests. The Hubalta core (core Z) takes on a "squashed" appearance, which is characteristic of finer textured more cohesive materials, but the Cooking Lake till (core X) contains definite shear planes which are more pronounced than those found in the Breton till (core Y). It is difficult to explain why the Cooking Lake cores do not have sharp failure points similar to the Breton cores since a shear plane is very evident in Plate 1. Possibly the binding action of sand grains in the lower part of the shear plane prevents further slippage and complete failure, thus giving a stress-strain curve similar to the finer textured Hubalta till.

The determinations for unconfined shear strength on the Lobley till samples is highly variable within sites as well as between different sites. Failure occurred at a maximum of 41.8 p.s.i. at site 13 and at a minimum of 10.8 p.s.i. at site 12. The large amount of variability in shear strength can be explained by the variability in texture and a relatively high stone content. Cores were difficult to obtain, in this till, because of the high stone content.

Depth of Soil Profile: Dilute HCl was used to determine the depth of the overlying soil profile. The Breton and Hubalta profiles are significantly deeper than the Cooking Lake and Lobley profiles (Table 12). The Hubalta profile has the greatest variability with a range of 38 to 72 inches. The Cooking Lake profile has the least discrepancy, with a range of 35 to 37 inches (Appendix A, Table IIc). The deviations from the means is shown graphically in Figure 6.

The shallow soil profile developed from the Lobley till may be explained by the higher calcium carbonate content in the till. Ehrlich et al (1955) found that generally a shallower profile resulted when inorganic carbonate content increased. The depth of the Cooking Lake profile may be influenced by the salinity of the underlying bedrock, since the calcium carbonate content is only slightly higher in the Cooking Lake till than in the Hubalta and Breton tills. There are numerous factors which can effect the depth of a profile, among them texture, lime content, groundwater, underlying bedrock, topography and position, time of development, and vegetation may be the most important.

Real Specific Gravity: Buckman and Brady (1960) report that most mineral soils usually vary in specific gravity within the narrow limits of 2.60 and 2.75. This occurs because quartz, feldspar and

colloidal silicates, with densities within this range, usually make up the major portion of the mineral soils.

There is no significant differences in specific gravity of the 4 tills studied (Table 12). The slightly lower specific gravity value obtained for the Hubalta till group is probably due to a higher clay and lower sand content than the other 3 tills. Berry and Mason (1959) state that montmorillonite has a density of 2.0 to 2.7, decreasing with water content. Since water was used as the liquid media in the determinations, the specific gravity could conceivably be lower with samples higher in clay.

<u>Distribution of Coarse Fragments</u>: The coarse fragment distribution of the 4 representative tills are shown in Table 13. The results indicate that the till groups studied in west-central Alberta contain fragments mainly of the smaller fraction. Approximately 95 per cent of the coarse fragments are smaller than 8 m.m. in size suggesting that the tills are derived mainly from soft underlying bedrock in west-central Alberta.

The Hubalta and Breton tills have very similar distribution of their coarse fragments, however the Hubalta till was found to be more variable. In the Cooking Lake till 92 per cent of the particles are less than 4 m.m. and greater than 2 m.m. in size.

In general the Lobley till was found to be significantly different than the other 3 tills in distribution of coarse particles. There is a significantly greater percentage of rock fragments in the <32 and >16 m.m. fraction and <16 and >8 m.m. fraction. The higher content of coarser particles in the Lobley till may be due to shorter distance of transport since the Lobley till was deposited from the

TABLE 13 - Statistical Analyses for the Coarse Fragment Distribution of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	<128mm.* >64mm. (%)	<64mm.* >32mm. (%)	<32mm.* >16mm. (%)	<16mm.* >8mm. (%)	<8mm.* >4mm. (%)	<4mm.* >2mm. (%)
Cooking Lake Till 1-5	5	.008±.008	.026±.011	.160±.059	1.53±.46	6.4±1.6	91.8±2.0
Breton Till 6-10	5	.022±.027	.028±.044	.282±.180	1.81±.59	13.0±4.0	84.9±4.3
Lobley Till 11-15	5	.020±.012	.104±.025	.694±.169	4.46±.49	19.2±2.2	75.6±2.6
Hubalta Till 16-22	7	.026±.044	.143±.181	.429±.229	2.75±1.60	14.2±6.7	82.4±8.3

B. Significant Differences as Determined by Duncan's Multiple Range Test***

<128mm.** >64mm. (%)	<64mm.** >32mm. (%)	<32mm.** >16mm. (%)	<16mm.** >8mm. (%)	<8mm.** >4mm. (%)	<4mm.** >2mm. (%)
No Significant Difference	No Significant Difference	Lob.-Ck.	Lob.-Ck.	Ck.-Lob.	Lob.-Ck.
		Lob.-Bn.	Lob.-Bn.	Ck.-Hub.	Ck.-Hub.
		Lob.-Hub.	Lob.-Hub.	Ck.-Bn.	Lob.-Bn.
		Hub.-Ck.			Lob.-Hub.
F=0.37	F=1.69	F=8.35	F=8.47	F=6.92	F=7.75

* Per Cent (%) by number
** Ranked according to decreasing levels of significance
*** 95% confidence limits

Cordilleran ice sheet while the other 3 tills were deposited from the Continental ice sheet.

Initial field observations of the 4 tills under study suggest that preglacial gravels (quartzites) have been incorporated into the tills to some extent. However very few of the particles classified according to size were observed to be quartzites, suggesting only slight incorporation of preglacial gravels in the tills. The quartzites are mainly found in the coarser fraction, generally being greater than 16 mm. in size. The majority (99%) of the particles in the 4 tills studied are less than 16 mm. in size. Quartzites do not dominate the smaller fractions to any extent possibly because they are not weathered or disintegrated as readily as the softer underlying bedrock. The biased eye of an observer will generally pick only the larger stones and thus give an unrealistically high percentage of quartzites.

Pebble Count: The composition of pebbles found in glacial till reflect in part the source area for the material. Large numbers of igneous and metamorphic pebbles suggest that the pebbles have been largely transported by ice from the Canadian Shield, while large numbers of pebbles of Cretaceous and Tertiary origin suggest local bedrock sources for the materials (Bayrock, personal communication). The absence of high grade crystalline metamorphic and igneous pebbles suggests that the till is derived from the Cordilleran ice which flowed out of the Rocky Mountains. Some low grade crystalline metamorphic pebbles such as talcose schist may be present (Roed et al, 1967).

The results in Table 14 suggest that the 3 Continental tills, Hubalta, Cooking Lake and Breton cannot be differentiated on the basis of pebble counts. The Cordilleran till (Lobley) contains a

significantly higher limestone content and a significantly lower granite content than the 3 Continental tills. The high limestone content in the Lobley till suggests that this till was deposited by a glacier or glaciers which overrode a limestone subcrop. The very low granite content in the Lobley till is similar to findings reported by Roed et al (1967), Stalker (1956), and Gravenor and Bayrock (1955), for Cordilleran tills in Alberta. They report that Cordilleran tills do not contain any high grade metamorphic and igneous pebbles.

The data in Table 14 suggests that underlying bedrock is not always reflected in the composition of the tills. For example the Breton till is underlain by soft Paskapoo sandstone, however the quantity of sandstone pebbles present in the parent material is relatively low. This could be a misconception because pebbles larger than 10 mm. were generally selected for classification. Since the pebbles are generally variable in their resistance to weathering and mechanical decomposition, the softer sandstones and shales may have broken down to finer sizes. It was shown previously that 95 per cent of the pebbles in the tills studied are less than 8 mm. in size. This finer fraction does contain an appreciable amount of softer fragments such as shale and sandstone, which reflect the underlying bedrock. However, because of their size the majority of these pebbles were not selected for classification. In the future it would be more realistic to classify the composition of pebbles according to different size fractions.

Pebbles classified as "Others" in Figure 9 and Table 14 include iron concretions, siltstones, shales, gneiss, schist, coal, chert, flint and quartz. This group was later divided into various new categories because of the relatively high percentage in the

TABLE 14 - Statistical Analyses for the Pebble Count Distribution of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	Limestones* (%)	Sandstones* (%)	Dolomites* (%)	Quartzites* (%)	Granites* (%)	Others* (%) ●	Quartzites* + Sandstones (%)
Cooking Lake Till 1-5	5	13.2±6.4	22.0±2.5	2.1±2.5	28.7±5.3	13.7±6.7	20.3±3.5	50.8±5.9
Breton Till 6-10	5	4.3±8.6	23.4±5.0	0.1±0.1	41.0±12.0	9.2±5.0	22.1±5.8	64.4±12.9
Lobley Till 11-15	5	36.7±6.9	17.8±8.0	0.8±0.8	36.6±12.4	0.2±0.1	7.9±5.4	54.5±6.6
Hubalta Till 16-22	7	10.5±11.7	24.8±15.7	1.1±1.4	30.7±11.8	14.2±4.0	18.7±4.6	55.5±16.2

B. Significant Differences as Determined by Duncan's New Multiple Range Test***

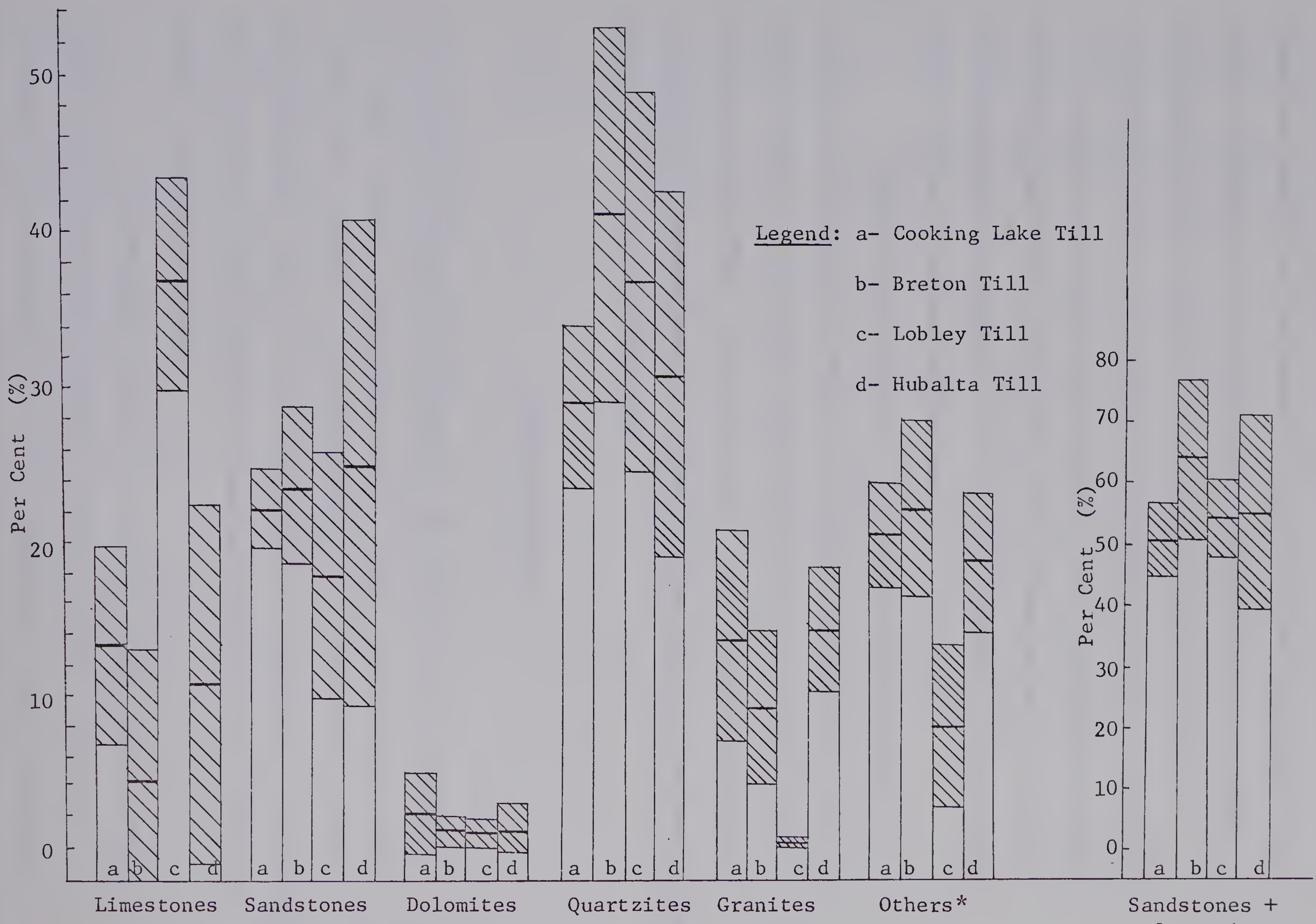
Limestones** (%)	Sandstones** (%)	Dolomites** (%)	Quartzites** (%)	Granites** (%)	Others** (%)	Quartzites** + Sandstones (%)
Lob.-Bn.	No Significant Difference	No Significant Difference	No Significant Difference	Lob.-Hub.	Lob-Bn.	No Significant Difference
Lob.-Hub.				Lob.-Ck.	Lob.-Ck.	
Lob.-Ck.				Lob.-Bn.	Lob.-Hub.	
F=12.46	F=0.48	F=1.57	F=1.37	F=10.59	F=8.60	F=1.84

* Per Cent (%) by number
** Ranked according to decreasing levels of significance
*** 95% confidence limits
● For pebble composition see Table 14A

TABLE 14A - Pebble Composition of those Classified as "Others" in Table 14*

Sample Number		Iron Concretions (%)	Crystalline** Metamorphic (%)	Siltstones (%)	Others*** (%)	Igneous + Metamorphic**** Crystalline (%)
1	Ck.	7.2	6.0	-	5.2	17.2
2	Ck.	5.3	11.8	-	4.8	22.3
3	Ck.	12.3	2.9	-	5.3	17.2
4	Ck.	1.3	7.5	2.2	4.7	32.5
5	Ck.	7.9	7.9	-	9.2	15.5
Mean and S.D.		6.80±4.00	7.22±3.23	0.44±0.98		20.94±6.50
6	Bn.	7.4	0.6	-	12.9	11.0
7	Bn.	6.8	6.8	-	3.4	13.1
8	Bn.	5.8	9.8	1.8	4.3	16.3
9	Bn.	7.4	7.1	-	4.5	24.5
10	Bn.	6.3	0.3	23.6	1.8	5.5
Mean and S.D.		6.74±0.70	4.92±4.25	5.08±10.38		14.08±7.03
11	Lob.	0.6	0.3	1.8	0.8	0.6
12	Lob.	1.7	0.3	7.9	0.9	0.6
13	Lob.	0.5	-	14.7	0.8	-
14	Lob.	0.6	-	2.6	0.3	0.3
15	Lob.	0.7	-	1.6	3.4	0.2
Mean and S.D.		0.82±0.50	0.12±0.16	5.72±5.60		0.34±0.26
16	Hub.	6.0	5.1	-	11.7	19.0
17	Hub.	5.8	7.2	-	3.2	26.0
18	Hub.	3.6	10.4	-	8.7	24.1
19	Hub.	11.4	3.1	-	1.9	14.6
20	Hub.	5.6	4.5	2.8	6.0	15.6
21	Hub.	3.3	3.7	-	3.7	13.4
22	Hub.	10.0	8.6	-	4.5	29.1
Mean and S.D.		6.53±3.07	6.09±2.72	0.40±1.06		20.26±6.17

* Based on summation of total pebbles counted
** Comprised mainly of gneiss and schist
*** Comprised mainly of chert, flint, coal,and quartz
**** Comprised of granite, gneiss, and schist



* For composition see Table 14A

Figure 9 -Histograms Showing the Means and Standard Deviations for Pebble Count of the Reference Tills

Continental tills. Sample results, means and standard deviations for these new categories, are shown in Table 14A. The Continental tills show no difference in iron concretion, siltstone, and crystalline metamorphic pebble content. The relatively high percentage of crystalline igneous plus crystalline metamorphic pebbles substantiate that the Hubalta, Cooking Lake and Breton tills are derived from the Continental ice sheet. The Lobley till is characterized by a high limestone content, essentially no crystalline igneous and metamorphic pebbles and very few iron concretions.

The Hubalta and Breton tills contain a great deal of variability in limestone content as is shown in Appendix A, Table VIc and in Figure 9. The large variability likely reflects the distant source area from where these pebbles were derived and the quantity of rock material incorporated into the body of the ice and subsequently transported to the point of deposition.

Chemical Analyses

pH and Calcium Carbonate Equivalent: The pH and calcium carbonate equivalent reflects the presence of free lime in the parent material of the tills studied. The pH ranged from 7.2 in the Hubalta, Breton and Cooking Lake tills to 7.9 in the Lobley till (Appendix A, Table VIIc). The 4 tills are mildly alkaline in reaction with Lobley till generally having a slightly higher pH.

The moderately calcareous Lobley till has a significantly higher calcium carbonate equivalent than the 3 weakly calcareous Continental tills (Table 15). Similar results have been reported by Pawluk (1961) and Roed (1968) for tills generally found in the same regions.

TABLE 15 - Statistical Analyses for the Distribution of Some Chemical Characteristics of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	$CaCO_3$ (%)	C.E.C. me./100g.	Dithionate extractable Fe and Al: Fe (%)	Al (%)	Fe + Al (%)
Cooking Lake Till 1-5	5	4.14±1.68	14.1±1.7	0.73±.08	0.13±.08	0.86±.07
Breton Till 6-10	5	3.76±1.60	19.4±0.9	0.71±.05	0.08±.01	0.79±.06
Lobley Till 11-15	5	10.40±2.76	16.6±2.7	0.72±.06	0.09±.004	0.81±.06
Hubalta Till 16-22	7	3.19±0.89	20.9±0.7	0.83±.11	0.12±.08	0.94±.13

B. Significant Differences as Determined by Duncan's New Multiple Range Test*

$CaCO_3$** (%)	C.E.C.** me./100g.	Fe** (%)	Al** (%)	Fe + Al** (%)
Lob.-Hub.	Hub.-Ck.	No Significant Difference	No Significant Difference	Bn.-Hub.
Lob.-Bn.	Ck.-Bn.			Hub.-Lob.
Lob.-Ck.	Hub.-Lob.			
	Bn.-Lob.			
	Lob.-Ck.			
F=18.95	F=19.55	F=2.88	F=0.61	F=3.42

** Ranked according to decreasing levels of significance
* 95% confidence limits

<u>Cation Exchange Capacity</u>: The finer textured Hubalta till has a higher cation exchange capacity, than the other 3 tills. The coarser textured Cooking Lake till has the lowest exchange capacity values. There are generally significant differences in cation exchange capacity between the 4 tills studied. However the Hubalta-Breton till is an exception (Table 15).

Buckman and Brady (1960) report that a rough correlation exists between texture and cation exchange capacity, the latter, in general, increasing for soils with finer texture. The Breton and Cooking Lake tills have similar clay content but the cation exchange capacity is significantly higher in the Breton till. The abnormally high values obtained for the Breton till is the result of a significantly higher percentage of montmorillonite as compared to the remaining 3 tills, thus giving cation exchange values which approach the finer textured Hubalta till.

There is a correlation of texture and cation exchange capacity in the variable Lobley till group. Samples 14 and 15 have the highest exchange capacity values and are finer textured than the remaining Lobley till samples (Appendix A, Table Ic and VIIc).

<u>Extractable Iron and Aluminum</u>: There is no significant difference in dithionate extractable iron and aluminum in the Hubalta, Breton, Cooking Lake, and Lobley tills (Table 15). The Hubalta till is significantly higher in iron plus aluminum than the Lobley and Breton tills, but the low F value suggests that large differences do not occur. Dithionate extractable iron and aluminum generally cannot be used to differentiate the 4 tills studied.

<u>Electrical Conductivity and Soluble Salts</u>: Electrical conductivity and soluble salts analyses are reported in Table 16. The electrical

TABLE 16 - Statistical Analyses for the Electrical Conductivity and Soluble Salts Distribution of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	Electrical Conductivity (mmhos/cm.^{2})	Soluble Salts (me./litre)			
			Na^+	K^+	Mg^{++}	Ca^{++}
Cooking Lake Till 1-5	5	0.44±0.07	1.29±0.34	0.14±0.06	1.38±0.31	7.63±1.82
Breton Till 6-10	5	0.28±0.06	0.95±0.30	0.10±0.05	0.95±0.21	8.65±1.82
Lobley Till 11-15	5	0.27±0.08	0.93±0.31	0.07±0.02	1.05±0.13	9.10±0.58
Hubalta Till 16-22	7	0.31±0.13	1.17±0.62	0.08±0.03	1.05±0.38	7.95±2.12

B. Significant Differences as Determined by Duncan's New Multiple Range Test*

Electrical* Conductivity (mmhos/cm.^{2})	Soluble Salts (me./litre)**			
	Na^+	K^+	Mg^{++}	Ca^{++}
Ck.-Lob.	No Significant Difference	No Significant Difference	No Significant Difference	No Significant Difference
Ck.-Bn.				
Ck.-Hub.				
F=3.37	F=0.79	F=2.79	F=2.21	F=0.76

** Ranked according to decreasing levels of significance
* 95% confidence limits

conductivity of the 4 tills is low and can be classified as nonsaline. The Cooking Lake till has a significantly higher electrical conductivity than the other 3 tills which may at least in part reflect the underlying saline bedrock formation and/or groundwater effects.

There is no significant difference in soluble cations among the 4 tills studied. Ca^{++} was found to be the dominant soluble cation in all the tills indicating the presence of free lime in the C horizon. The Cooking Lake till has the highest soluble Na^{+} content. The slightly higher Na^{+} content may explain the slight solodic characteristics described by various workers for the Cooking Lake soil Series (Lindsay et al, 1968; Bowser et al, 1962).

Mineralogical Analyses

Clay Mineralogical Analyses: Semi-quantitative estimations of clay minerals in the total clay fraction of the 4 glacial till groups were made using X-ray diffraction data as well as chemical and physical analysis.

X-ray diffraction patterns of calcium saturated total clay separated from the glacial tills are included in Figures 10 to 13. The statistical data for physical and chemical analyses of these clays are presented in Table 17. The physical and chemical analyses for the individual samples comprising the 4 groups of till together with estimations of their relative amounts are presented in Table 17A.

Estimates of the amounts of illite and montmorillonite present in the clay fraction separated from the glacial till samples were calculated on the basis of K_2O content, cation exchange capacities, and surface area determinations. The illite content was determined by

assigning all the potassium to illite and assuming illite to have a K_2O content of 10 per cent (Mehra, 1959). Once the amount of illite present had been calculated and by assigning to it a cation exchange capacity of 20 me. /100 g. and a surface area of 10 m. ^{2}/g., it was possible to estimate the amount of montmorillonite on the basis of the remaining portions of the exchange capacity and surface areas. A cation exchange capacity of 89 me. /100 g. and a total surface area of 980 m.^{2}/g. were assigned to montmorillonite thereby making it possible to calculate the montmorillonite content of the clays by two methods. The relative amounts of kaolinite, chlorite and quartz were based on examination of X-ray diffractograms.

In general, the clay fraction of the 4 tills consists predominantly of a montmorillonite species and illite. Lesser amounts of chlorite, kaolinite and quartz were found in all the tills. The cation exchange capacity of the clay separated from the Breton till is significantly higher than the other groups of till, indicating a higher percentage of montmorillonite (Table 17). The surface area of the clay separated from the Lobley till is significantly lower than the other 3 tills indicating a lower percentage of montmorillonite in the Lobley till. Breton till has a higher montmorillonite content than the Cooking Lake till as determined by both surface area and cation exchange capacity. The average percent montmorillonite as determined by cation exchange capacity and surface area (Table 17) indicates that Breton till has a significantly greater content than the other 3 tills and that the Hubalta till clay fraction contains more montmorillonite than the Lobley till.

There is good agreement between cation exchange capacity and

TABLE 17 - Statistical Analyses for Clay Mineral Determinations of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of Rep's.	C.E.C. me./100g.	Surface Area $m.^2/g.$	K_2O (%)	% Montmorillonite (1)	% Montmorillonite (2)	% Montmorillonite (Mean)
Cooking Lake Till 1-5	5	48.3±3.9	502.8±49.1	1.97±0.25	49.0±4.2	50.2±5.1	49.4±4.6
Breton Till 6-10	5	56.5±2.1	563.6±44.3	2.05±0.27	58.2±2.7	56.2±4.4	57.6±3.4
Lobley Till 11-15	5	49.9±3.7	409.4±30.0	2.77±0.29	49.4±4.7	40.6±3.2	45.0±3.8
Hubalta Till 16-22	7	51.3±3.0	532.9±31.3	2.20±0.59	52.1±4.6	53.3±3.0	52.6±3.5

B. Significant Differences as Determined by Duncan's New Multiple Range Test*

C.E.C** me./100g.	Surface Area** $m.^2/g.$	K_2O** (%)	% Montmorillonite** (1)	% Montmorillonite** (2)	% Montmorillonite** (Mean)
Bn.-Ck.	Lob.-Bn.	Lob.-Ck.	Bn.-Ck.	Lob.-Bn.	Lob.-Bn.
Bn.-Lob.	Lob.-Hub.	Lob.-Bn.	Bn.-Lob.	Lob.-Hub.	Lob.-Hub.
Bn.-Hub.	Lob.-Ck.	Lob.-Hub.	Bn.-Hub.	Lob.-Ck.	Bn.-Ck.
	Bn.-Ck.			Bn.-Ck.	Bn.-Hub.
F=6.11	F=15.21	F=3.92	F=5.12	F=15.24	F=9.83

(1) Montmorillonite values based on cation exchange capacity data
(2) Montmorillonite values based on surface area data

* 95% confidence limits

** Ranked according to decreasing levels of significance

TABLE 17A - Clay Mineral Determinations of the Reference Till Samples

Sample Number		C.E.C.** (me./100g.)	Surface*** Area (m.^{2}/g.)	K_2O (%)	Montmorillonite (%) (1)	Montmorillonite (%) (2)	Mont. (mean) (%)	Illite (%)	Chlorite* (%)	Kaolinite* (%)	Quartz* (%)
1	Cooking Lake Till	50.1	546	2.11	51	54	52	21	5-10	0-10	2-6
2		52.5	550	2.32	53	56	54	23	5-10	0-10	2-6
3		50.5	516	1.69	52	51	52	17	5-10	0-10	2-6
4		44.7	448	1.91	45	45	45	19	5-8	0-10	2-6
5		43.5	454	1.80	44	45	44	18	10-20	0-10	2-6
6	Breton Till	54.3	580	2.17	56	58	57	22	5-10	0-5	2-6
7		57.8	591	1.85	60	59	60	18	5-10	0-5	2-6
8		55.2	513	2.38	56	51	54	24	5-8	0-10	2-6
9		55.9	521	2.17	57	52	55	22	5-8	0-10	2-6
10		59.4	613	1.70	62	61	62	17	5-8	0-10	2-6
11	Lobley Till	53.5	449	2.62	54	45	49	26	5-10	0-10	2-6
12		44.6	373	3.24	43	37	40	32	10-20	0-10	2-6
13		51.5	422	2.56	51	42	47	26	5-10	0-10	2-6
14		47.5	387	2.88	46	38	42	29	5-8	0-15	2-6
15		52.5	416	2.56	53	41	47	26	5-8	0-15	2-6
16	Hubalta Till	52.0	564	2.17	53	56	55	22	10-20	0-5	2-6
17		52.0	550	2.38	52	55	53	24	0-5	0-10	2-6
18		46.9	480	2.56	46	48	47	26	5-10	0-5	2-6
19		56.5	552	0.90	61	55	58	9	0-5	0-5	2-6
20		51.7	521	2.26	53	52	52	23	0-5	0-10	2-6
21		49.0	506	2.62	49	51	50	26	5-10	0-10	2-6
22		51.1	557	2.50	51	56	53	25	5-10	0-10	2-6

1 Montmorillonite based on cation exchange capacity data
2 Montmorillonite based on surface area data
** Average value of duplicate determinations
*** Average value of triplicate determinations

* Estimates based on x-ray diffraction patterns

surface area for the estimation of the percentage montmorillonite in the 3 Continental tills, but surface area is consistently lower than cation exchange estimates for montmorillonite content in the Lobley till. Possibly cation exchange capacity and surface area estimates of 89 me. /100 g. and/or 980 $m.^2/g.$ for montmorillonite species in tills deposited by the Cordilleran ice is not realistic. Possibly a higher charged montmorillonite species is the major expansible clay mineral present in the Lobley till. This would give higher cation exchange capacity values with little or no effect on surface area values. Some preliminary investigations have suggested the presence of vermiculite in some tills of Cordilleran origin (Beke and Pettapiece, personal communication).

The Lobley till is characterized by a significantly higher percentage of illite and lower percentage of montmorillonite than the 3 Continental tills. Estimates of illite percentage varied from 26 to 32 per cent.

The X-ray diffractograms for the various till samples are generally very similar with the exception of site 5 of the Cooking Lake till group, site 12 of the Lobley till group, and sites 16 and 18 of the Hubalta till group. At these sites the chlorite content was slightly higher than at other sites. The low K_2O content at site 19 of the Hubalta till group is unexplainable. The analysis was repeated 3 times with consistent low values. The glycolated X-ray diffractogram at site 19 indicates a poorly defined 10 Angstrom peak.

The presence of interstratified clay minerals in the 4 tills is suggested by the broad diffraction peak at 9.5 to 11 degrees 2θ for glycolated samples (Kodama and Brydon, 1965). For the 3 Continental tills this peak is quite pronounced, in some instances being almost

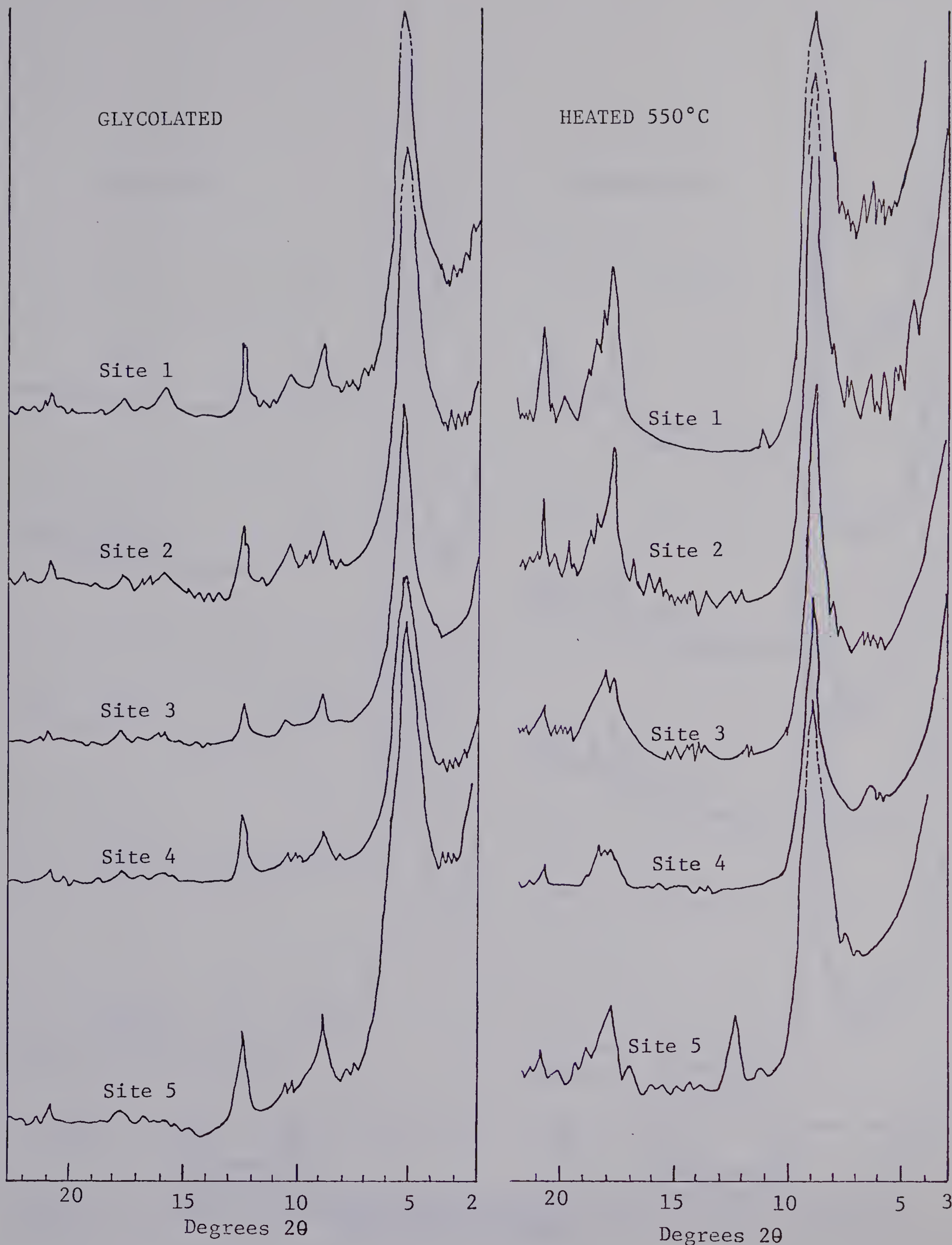


Figure 10 - X-ray Diffraction Patterns of Total Clay Separated from the Cooking Lake Till Samples

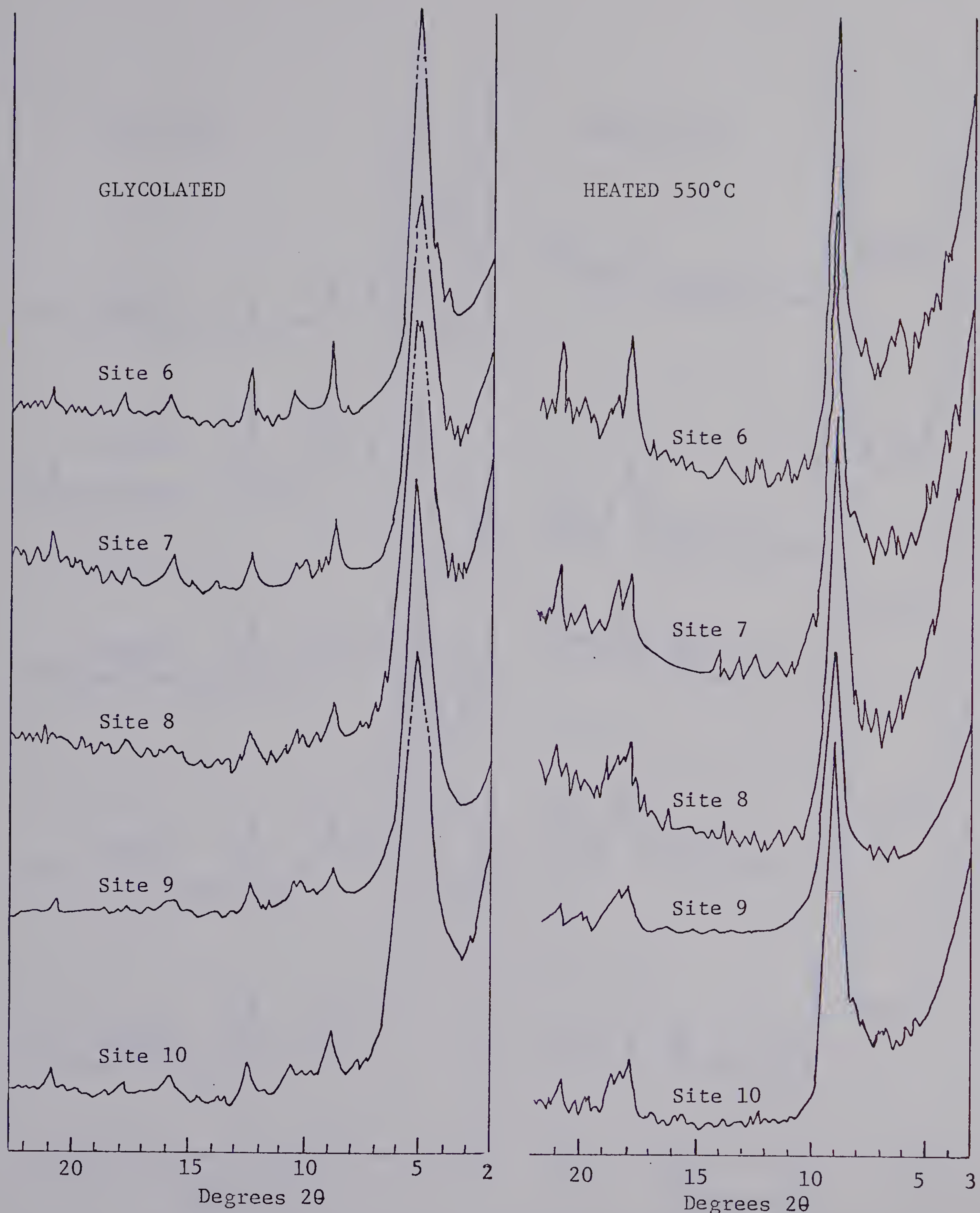


Figure 11 - X-ray Diffraction Patterns of Total Clay Separated from the Breton Till Samples

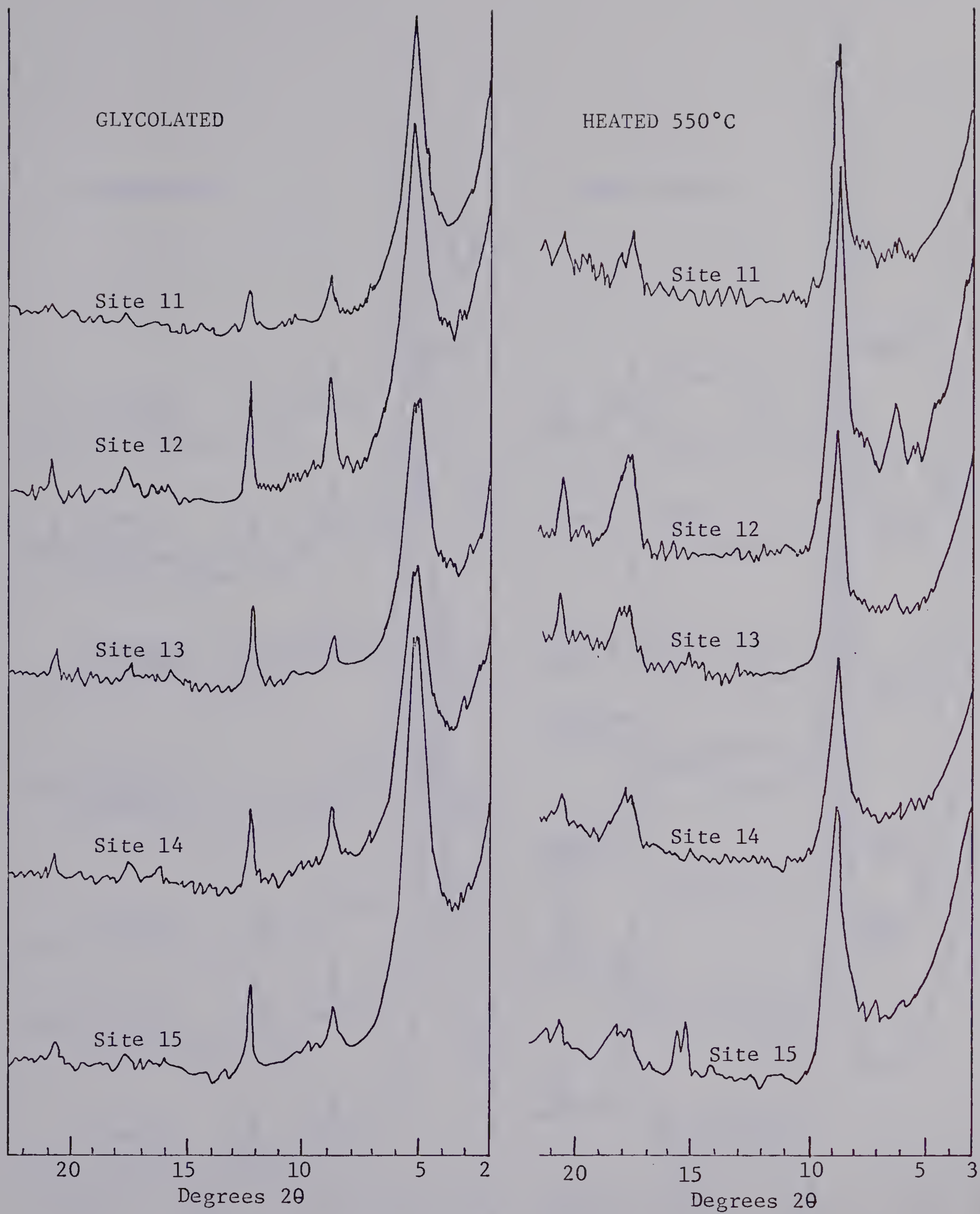


Figure 12 - X-ray Diffraction Patterns of Total Clay Separated from the Lobley Till Samples

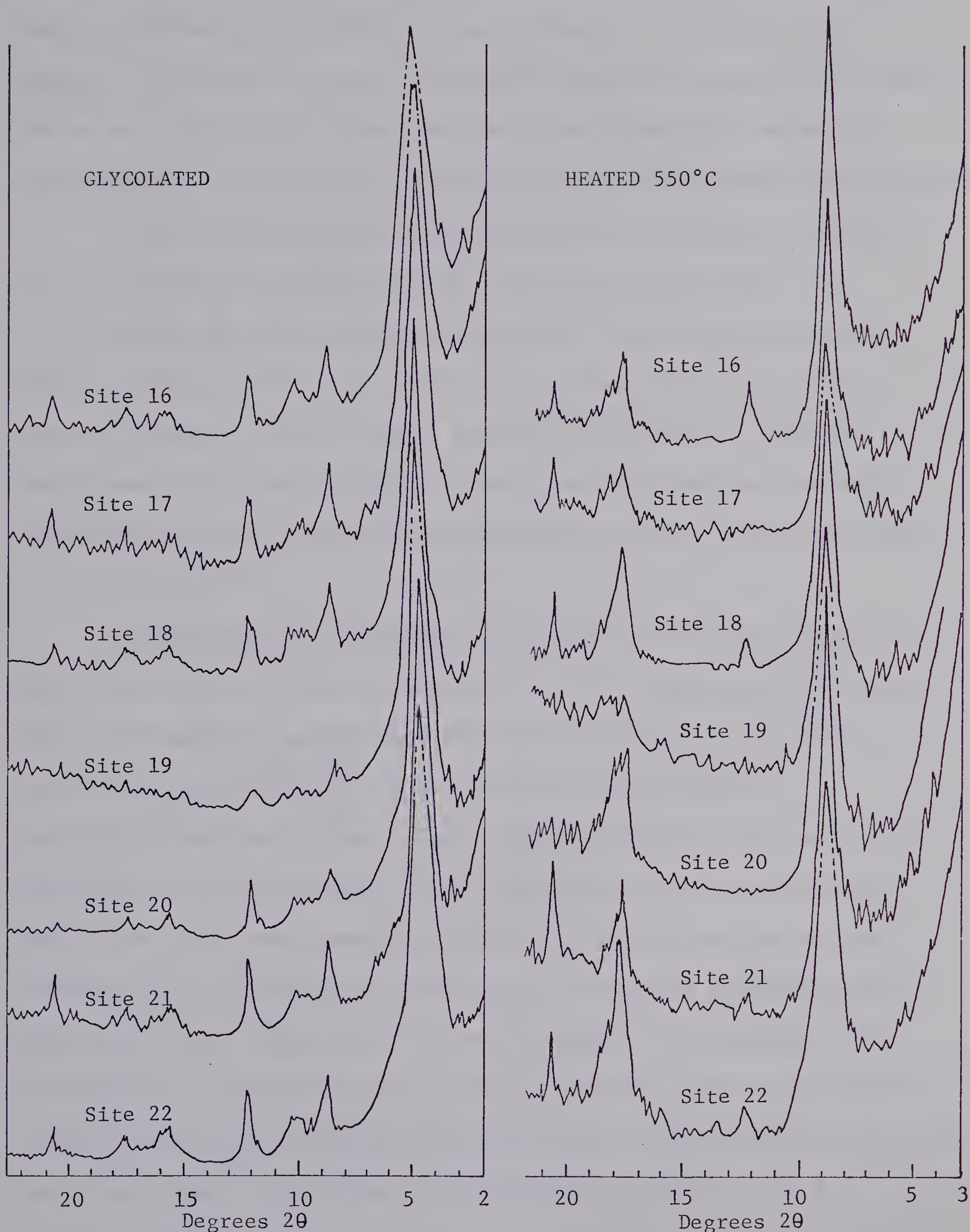


Figure 13 - X-ray Diffraction Patterns of Total Clay Separated from the Hubalta Till Samples

as intense as the illite peak. In the Lobley samples, the presence of interstratified clay minerals is less pronounced. In general the Hubalta till seems to contain the greatest amount of interstratification. Breton and Cooking Lake tills also contain an appreciable amount of interstratified clay but not to the same extent as the Hubalta till group.

That interstratified clay minerals exist in Western Canadian parent materials is verified by the work of Lavkulich (1963), and St. Arnaud et al (1963). Kodama et al (1965) conducted an intensive study of interstratified clay minerals from subsoils in the Canadian Prairie Provinces. Their results suggest the presence of randomly interstratified layers of montmorillonite and mica and that expansible layers are probably intermediate between montmorillonite and beidellite in composition.

Differential thermographs of the total clay fraction separated from the 4 tills are shown in Figures 14 to 17. The basic similarity of these thermographs suggests that the clay mineralogy of the 4 tills is generally somewhat similar. Some variation in the initial 2 endothermic peaks is evident. This variation reflects difference in hydration of the clay (Dudas, 1968). The endothermic deflection in the 660 to 690°C range generally correlates with the average per cent montmorillonite calculated by surface area and cation exchange capacity data (Table 17A). Generally the more pronounced the endothermic peak, the greater the montmorillonite content in the clay. The thermographs of the Lobley total clay fraction, reflect less intense initial endothermic peaks and a less intense peak in the 660-690°C range than the 3 Continental tills. The montmorillonite content in the Lobley till is lower than that found in the other tills.

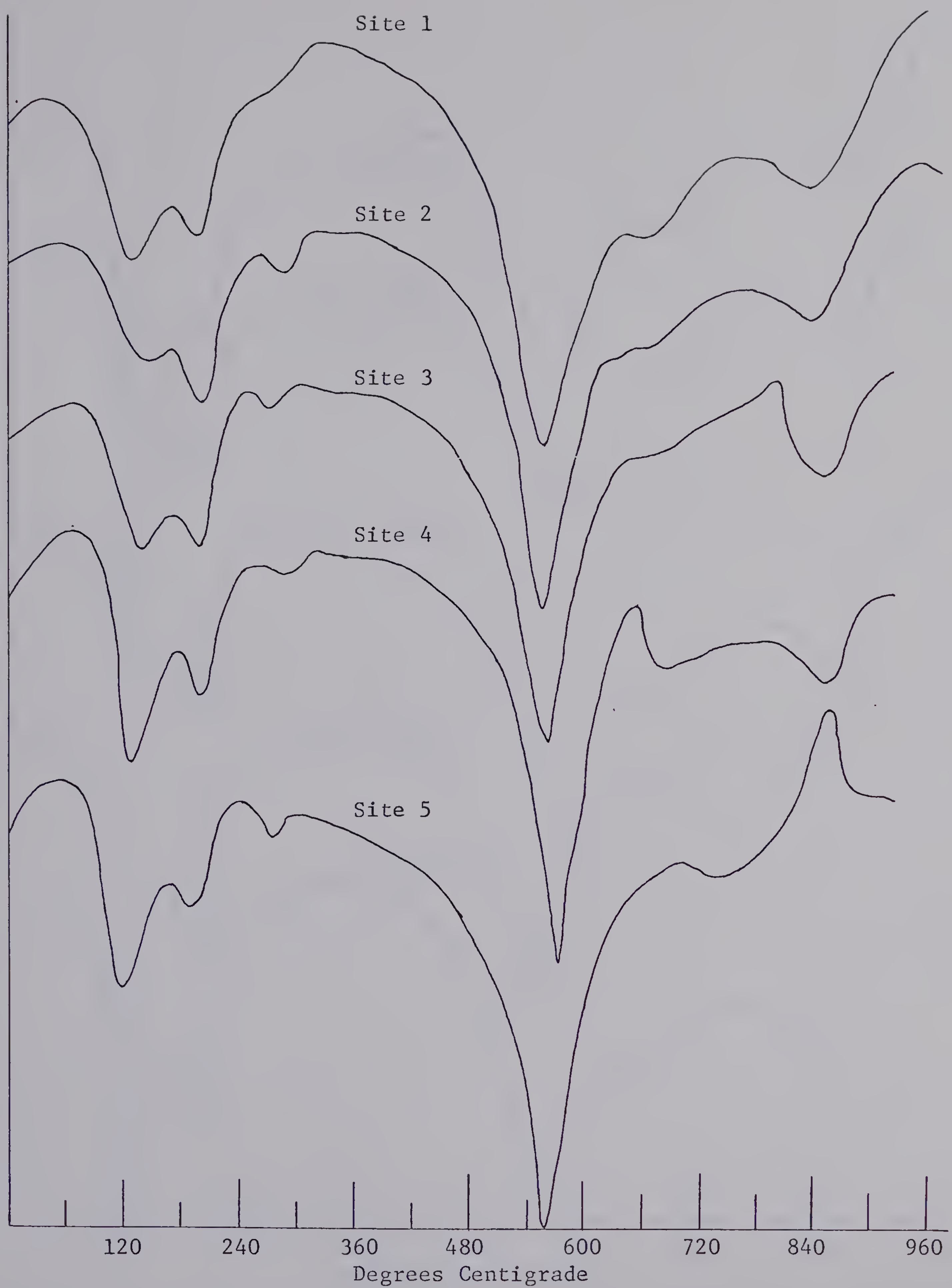


Figure 14 - Differential Thermographs of the Total Clay Fraction Separated from the Cooking Lake Till Samples

Figure 15 -Differential Thermographs of the Total Clay Fraction Separated from the Breton Till Samples

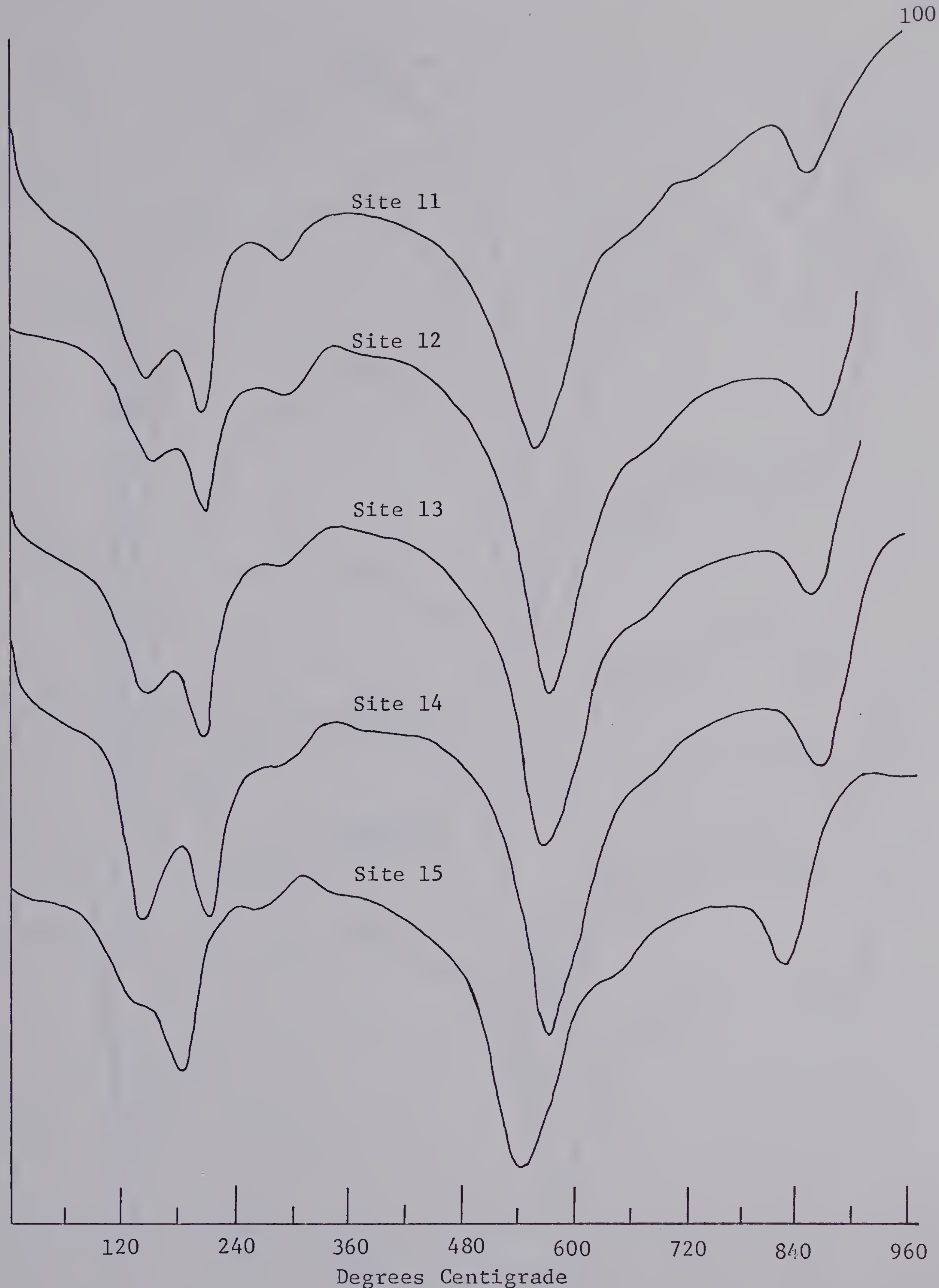


Figure 16 -Differential Thermographs of the Total Clay Fraction Separated from the Lobley Till Samples

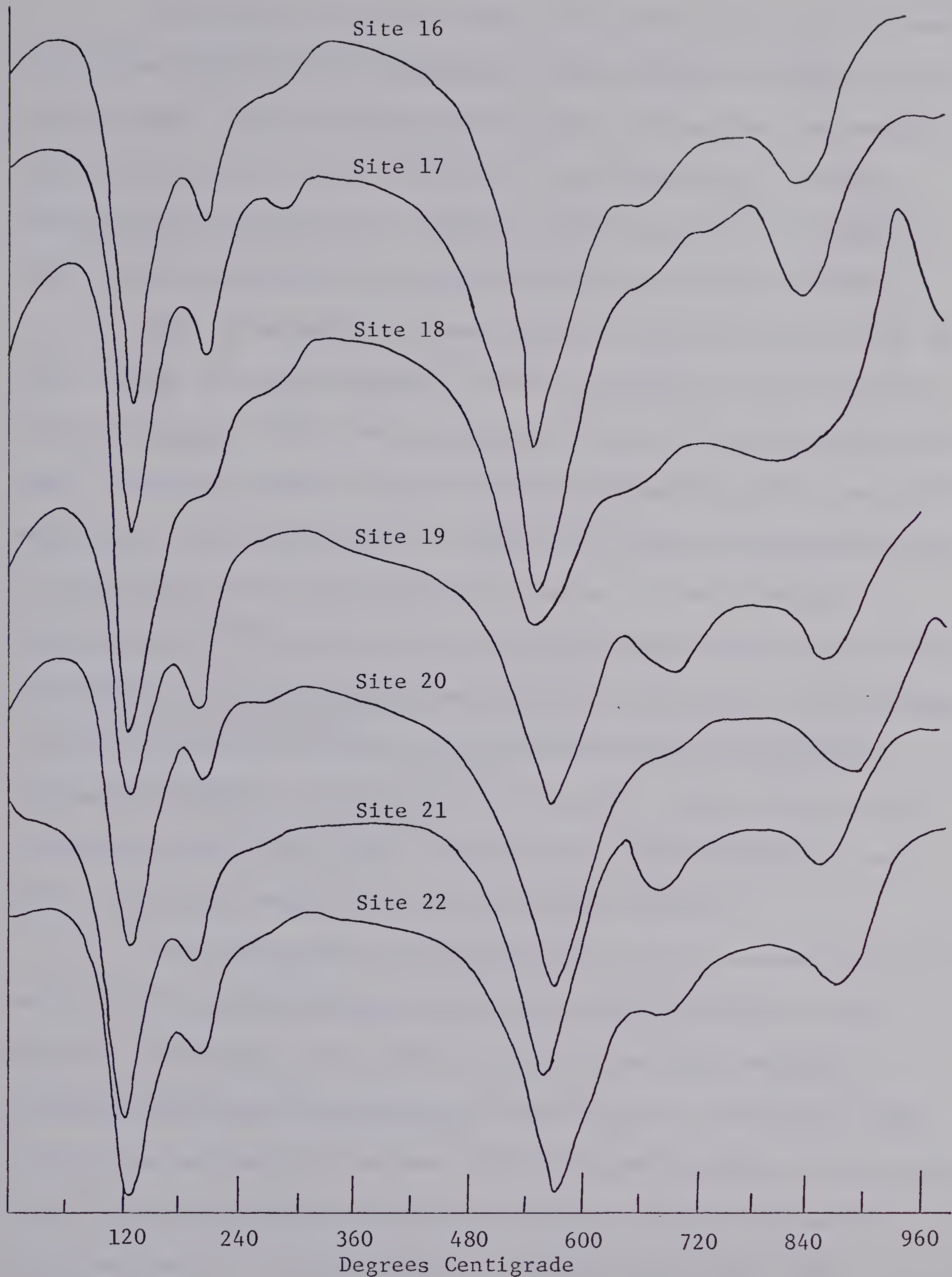


Figure 17 -Differential Thermographs of the Total Clay Fraction Separated from the Hubalta Till Samples

Generally the Breton, Hubalta and Lobley total clay thermographs are uniform, showing little discrepancy among individual samples comprising the groups. However thermographs for the Cooking Lake clay samples (Figure 14) indicate some variability in clay mineralogy. The high temperature exothermic peak of 850°C at site 5 suggests the presence of chlorite and substantiates the results obtained from X-ray analysis.

The thermographs all have hydroxyl endotherms between 540° and 590°C typical of illitic minerals. However "abnormal" montmorillonites (St. Arnaud _et al_, 1963; Kodama _et al_, 1965) also show peaks in the same range. Beidellite gives its main hydroxyl endothermic peak in the 550°C region (St. Arnaud _et al_, 1963). Arshad (1964) described montmorillonite in some Alberta soils as beidellitic in nature. Interstratified montmorillonite-illite also gives a 540°C endothermic peak (Coles, 1955). Very similar thermographs, to those reported in this study, were obtained by Kodama and Brydon (1965) for clays separated from till samples obtained from Alberta, Saskatchewan and Manitoba. These authors report endothermic peaks at 120°, 190° (shoulder) 535°, 650° (inflexion) and 880°C. Exothermic peaks were reported at 310° and 910°C.

The thermographs thus indicate the possible presence of illite and montmorillonite and interstratified montmorillonite-illite, and generally substantiate, the results obtained from X-ray analysis.

<u>Light and Heavy Mineral Separations</u>: The 0.114 m.m. to 0.25 m.m. sand fraction was separated by the heavy liquid flotation method into minerals heavier than and lighter than specific gravity 2.96 with the use of tetrabromoethane. The distribution of "light" (S.G.$<$ 2.96) and "heavy" (S.G.$>$2.96) minerals in the 4 till groups is shown in Table 18. The individual sample results comprising the 4 groups of till are shown

TABLE 18 - Statistical Analyses for the Light and Heavy Mineral Distribution of the Reference Till Samples

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	Light Minerals (S.G.< 2.96) (%)	Heavy Minerals (S.G.>2.96) (%)
Cooking Lake Till 1-5	5	98.97±0.30	1.03±0.27
Breton Till 6-10	5	99.12±0.12	0.88±0.03
Lobley Till 11-15	5	99.20±0.21	0.80±0.16
Hubalta Till 16-22	7	99.14±0.20	0.86±0.11

B. Significant Differences as Determined by Duncan's Multiple Range Test*

Light Minerals** (S.G.< 2.96) (%)	Heavy Minerals** (S.G.>2.96) (%)
No Significant Difference	No Significant Difference
F=0.43	F=1.90

* 95% confidence limits

** Ranked according to decreasing levels of significance

in Appendix A, Table IXc.

There is no significant difference in "light" and "heavy" mineral distribution in the 4 tills studied. Heavy mineral content is generally less than 1 per cent for all tills studied. Similar results were reported by Coen (1965) in the Stony Plain region of Alberta.

Light Mineral Analysis: Statistical quantitative estimates for the 0.114 m.m. to 0.25 m.m. sand fraction having a specific gravity less than 2.96 for the 4 groups of till are shown in Table 19. Quartz is the dominant mineral present in all the tills ranging from 66 to 81 per cent of the entire fraction (Appendix A, Table Xc). The soda-calcic feldspars are more abundant than the potassium feldspars in all 4 till groups. Among the various soda-calcic feldspars, the content of anorthite appears relatively low with the major portion of these minerals ranging from labradorite to albite.

The Cooking Lake till was found to be generally significantly lower in feldspar and higher in quartz content than the Hubalta and Breton tills. The lower feldspar content in the Cooking Lake till suggests a greater degree of weathering by dissolution of feldspars and/or a different bedrock source for the till.

The Lobley till which is known to be derived from a different source area generally shows no difference in light mineral distribution from the 3 Continental tills. The Hubalta, Lobley and Breton tills cannot be differentiated by light mineral distribution alone.

The Hubalta and Lobley tills show the greatest variability in feldspar and quartz content as illustrated in Figure 18.

Heavy Mineral Analysis: Statistical analyses for the heavy mineral distribution of the main minerals identified in the 4 groups of till are

TABLE 19 - Statistical Analyses for the Light Mineral Distribution of the Reference Till Samples
(S.G. < 2.96)

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	K Feldspar (%)	Soda-Calcic Feldspar (%)	Total Feldspar (%)	Quartz* (%)
Cooking Lake Till 1-5	5	6.6±1.5	13.6±2.1	20.2±3.4	79.8±3.4
Breton Till 6-10	5	9.6±0.9	20.0±2.4	29.6±3.2	70.4±3.2
Lobley Till 11-15	5	8.4±1.1	17.4±3.6	25.8±4.5	74.2±4.5
Hubalta Till 16-22	7	8.9±1.2	18.7±4.1	27.6±5.1	72.4±5.1

B. Significant Differences as Determined by Duncan's Multiple Range Test**

K Feldspar*** (%)	Soda-Calcic Feldspar*** (%)	Total Feldspar*** (%)	Quartz*** (%)
Ck.-Bn. Ck.-Hub. Ck.-Lob.	Ck.-Bn. Ck.-Hub.	Ck.-Bn. Ck.-Hub.	Ck.-Bn. Ck.-Hub.
F=5.64	F=3.64	F=4.60	F=4.60

* Determined by difference
** Ranked according to decreasing levels of significance
*** 95% confidence limits

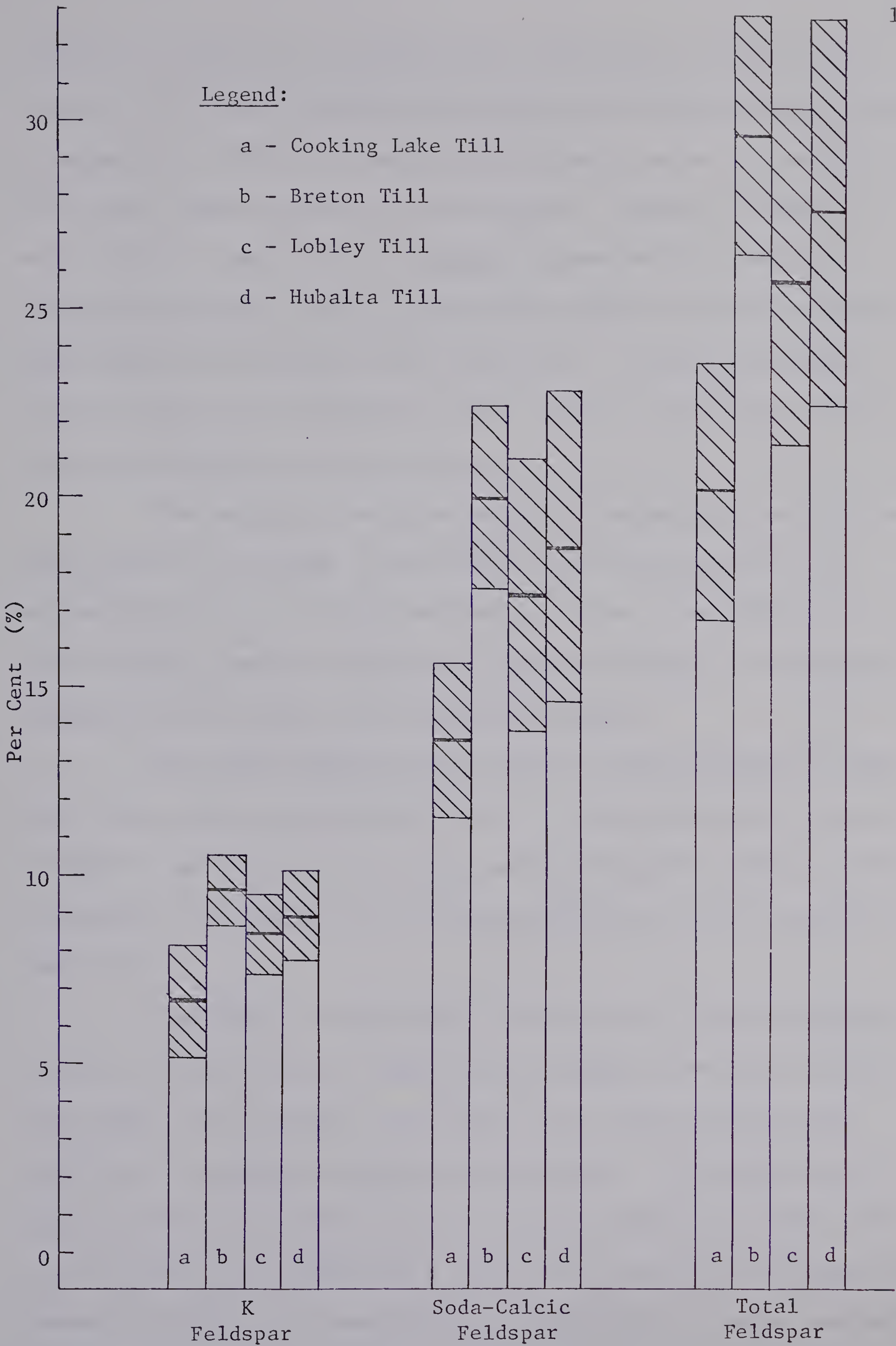


Figure 18 - Histograms Showing the Means and Standard Deviations for the Feldspar Distribution of the Reference Tills

presented in Table 20. All the minerals identified are tabulated as per cent of the total minerals counted (minimum of 300) and are presented in Appendix A, Table XIc. Heavy mineral identification was carried out on 6 Lobley samples instead of the original 5. Sample 15A which is very similar to sample 12 but contained a great deal of sandstone bedrock material was added to give a better idea of the variability of heavy mineral distribution in the Lobley till. Large discrepancies from the typical till occurred in other analyses carried out on this sample and therefore were not reported.

The relatively large percentage of unidentified minerals was mainly caused by coatings on the mineral grains which could not be removed by boiling in a dilute HCl-water solution. The Hubalta and Breton samples generally contained a larger percentage of unidentified minerals than the Lobley and Cooking Lake samples.

Only those minerals which appear to have differences among the 4 till groups are reported in Table 20. The minerals not reported in Table 20 generally occur in trace amounts among the 4 groups and do not appear to be diagnostic for differentiating the tills (Appendix A, Table XIc).

The results indicate that the Lobley till can be separated from the 3 other tills by a significantly higher percentage of total iron oxides, total opaques, and zircons, and a significantly lower percentage of amphiboles, garnets, and pyroxenes. The average total opaque content of the Lobley till is 73.3 per cent with a range of 53 to 87 per cent, thus indicating a great deal of variability (Figure 19); however the Lobley till does indicate a significantly greater percentage of opaques than the 3 Continental tills. The majority of the iron oxide

TABLE 20

TABLE 20 - Statistical Analyses for the Heavy Mineral Distribution of the Reference Till Samples

S.G. > 2.96

A. Means and Standard Deviations

Identification of Till Sample	# of rep's.	Total Fe* Oxides (%)	Total* Opaques (%)	Amphiboles* (%)	Garnets* (%)
Cooking Lake Till 1-5	5	37.2±9.7	41.4±10.9	27.6±8.0	10.8±2.2
Breton Till 6-10	5	45.2±9.3	52.2±8.6	10.8±3.3	8.2±3.4
Lobley Till 11-15A	6	58.5±10.8	73.3±12.2	0.7±0.8	3.8±3.1
Hubalta Till 16-22	7	39.7±7.9	44.4±7.4	13.0±3.9	11.0±3.3

B. Significant Differences as Determined by Duncan's New Multiple Range Test***

Total Fe** Oxides (%)	Total** Opaques (%)	Amphiboles** (%)	Garnets** (%)
Ck.-Lob.	Ck.-Lob.	Ck.-Lob.	Lob.-Hub.
Hub.-Lob.	Hub.-Lob.	Ck.-Bn.	Lob.-Ck.
Bn.-Lob.	Bn.-Lob.	Ck.-Hub.	Lob.-Bn.
		Hub.-Lob.	
		Bn.-Lob.	
F=6.02	F=12.6	F=31.82	F=7.07

* Per cent (%) of total minerals counted (minimum of 300 grains)

** Ranked according to decreasing levels of significance

*** 95% confidence limits

TABLE 20 - Statistical Analyses for the Heavy Mineral Distribution of the Reference Till Samples (Continued)

S.G.>2.96

A. Means and Standard Deviations

Epidote* (%)	Pyroxene* (%)	Chlorite* (%)	Zircon* (%)	Apatite* (%)	Tourmaline* (%)
3.4±0.5	2.6±0.5	0.7±0.3	0.8±0.2	0.6±0.3	0.7±0.3
7.0±2.9	1.3±0.6	1.3±0.6	0.9±0.3	0.9±0.7	0.4±0.4
5.0±2.1	0.4±0.8	1.9±1.2	2.3±1.2	0.3±0.3	0.6±0.5
6.4±1.1	2.0±0.6	1.9±0.9	1.1±0.6	1.5±0.7	0.6±0.4

B. Significant Differences as Determined by Duncan's New Multiple Range Test***

Epidote** (%)	Pyroxene** (%)	Chlorite** (%)	Zircon** (%)	Apatite** (%)	Tourmaline** (%)
Ck.-Bn.	Lob.-Ck.	No Significant Difference	Lob.-Ck.	Hub.-Lob.	No Significant Difference
Ck.-Hub.	Lob.-Hub.		Lob.-Bn.	Hub.-Ck.	
	Bn.-Ck.		Lob.-Hub.		
	Lob.-Bn.				
F=4.0	F=11.8	F=2.20	F=5.59	F=5.77	F=0.33

* Per cent of total minerals counted (minimum of 300 grains)

** Ranked according to decreasing levels of significance

*** 95% confidence limits

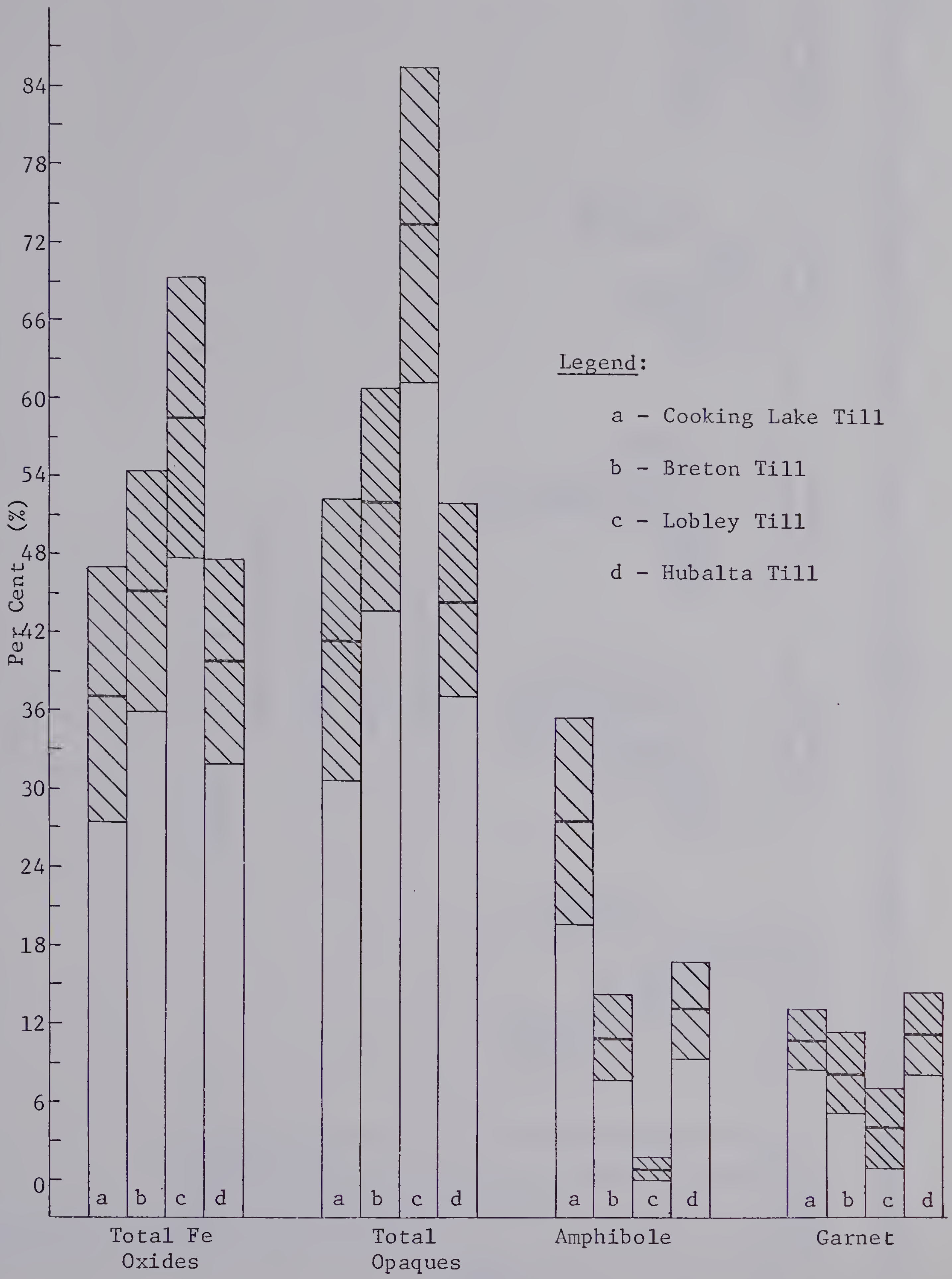


Figure 19 - Histograms Showing the Means and Standard Deviations for some of the Heavy Minerals of the Reference Tills

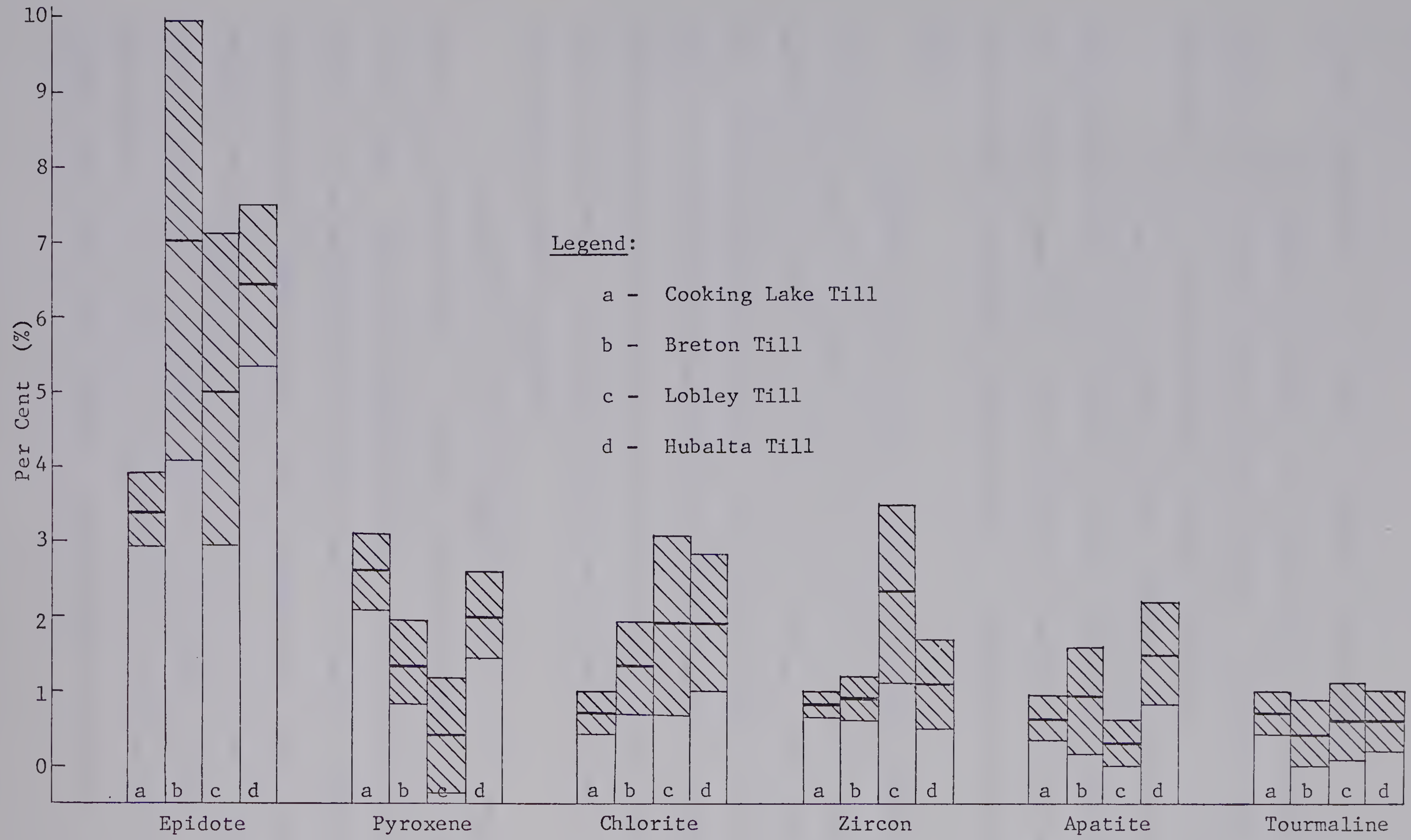


Figure 20 - Histograms Showing the Means and Standard Deviations for some of the Heavy Minerals of the Reference Tills

opaques identified in the 4 tills is hematite and limonite.

The amphibole content in the Lobley till is practically non-existent. Roed (1968) reported similar results. He suggests that Continental tills contain hornblende whereas Cordilleran tills do not.

In general the Cordilleran till, (Lobley) can be differentiated from the Continental tills, (Hubalta, Breton, and Cooking Lake) using heavy mineral assemblages. Heavy minerals in the tills are diagnostic of source area and support differentiation of respective tills (Roed, 1968).

Amphibole content proved to be one of the best criteria for differentiating the 4 groups of till. The very low amphibole content in the Lobley till (0-2%) and relatively high percentage in the Cooking Lake till (21-41%) differentiates these 2 tills from the Hubalta and Breton tills. The Hubalta and Breton tills have similar amphibole content. The Hubalta and Breton tills could not be differentiated on any of the heavy mineral constituents, indicating that they may be derived from lithologically similar bedrock formations.

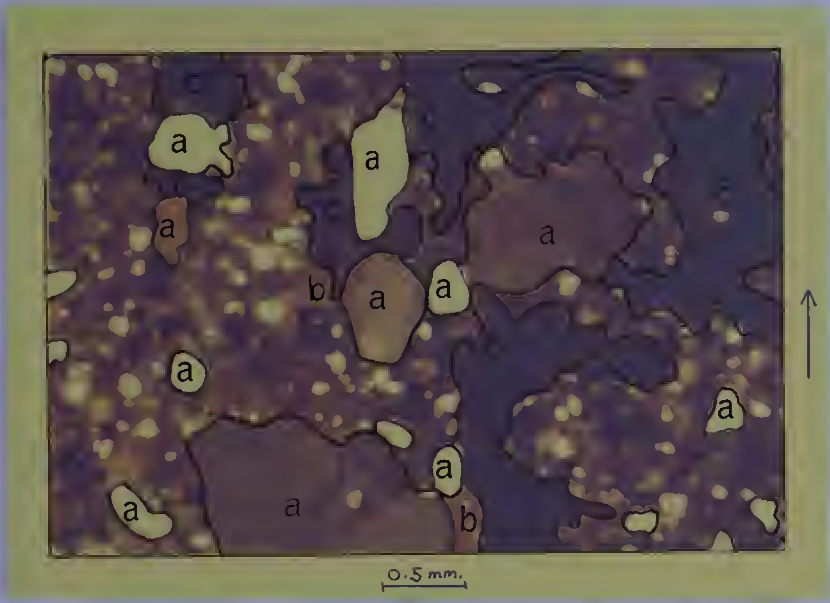
Bayrock (1962) reported amphibole content in till samples for east-central Alberta that are similar to the Cooking Lake till samples in this study. Since the underlying bedrock in east-central Alberta is similar to that underlying the Cooking Lake till samples, similar results can be expected. However Bayrock (1962) suggests that heavy mineral analyses are not diagnostic in differentiating tills in east-central Alberta derived from the Keewatin centre of glaciation, because approximately 95 per cent of the heavy minerals are derived from the Canadian Shield and only 5 per cent from the underlying bedrock.

Roed (1968) working in the Edson-Hinton area, which is adjacent to the Chip Lake map area, found a hornblende content in the Continental tills which was lower than that reported by Bayrock (1962). He suggests that the lower hornblende content is a result of "dilution" by other minerals because the ice in the area was at its maximum extent of expansion. A similar amphibole content is reported in this study for the Breton and Hubalta tills as is reported by Roed (1968), for Continental tills.

Micromorphology: Thin sections of some of the representative till samples were prepared and examined to determine whether or not differences in the microstructure exist among the 4 till groups studied. Typical photomicrographs are presented (Plates 2 to 6).

The terms used to describe the photomicrographs were adopted from Kubiena (1938) and Brewer (1964) and may be defined as follows:

> "Plasma of a soil material is that part which is capable of being or has been moved, reorganized, and/or concentrated by the processes of soil formation. It includes all the material, mineral or organic, of colloidal size and relatively soluble material which is not bound up in skeleton grains."
>
> "Skeleton grains of a soil material are individual grains which are relatively stable and not readily translocated, concentrated or reorganized by soil-forming processes."
>
> "Soil matrix consists of the plasma, skeleton grains, and voids that do not occur in pedological features



LEGEND (examples of:)

a Skeletal Grains

b Plasma

c Voids

Plate 2 - Photomicrograph of Cooking Lake till from Site 2 (Crossed nicols)

This photomicrograph illustrates the coarse character of Cooking Lake till. Skeletal grains commonly consist of quartz, chert, primary carbonates and rock fragments. They are poorly sorted, subangular to angular, and randomly distributed. The plasma is light buff in color, non-oriented and appears to be of uniform character. Voids are sinuous, well defined, and appear to form intricate, interconnected matrices. Voids make up approximately 20 per cent of the total matrix.

LEGEND (examples of:)

e Skeletal Grains

b Plasma

c Voids

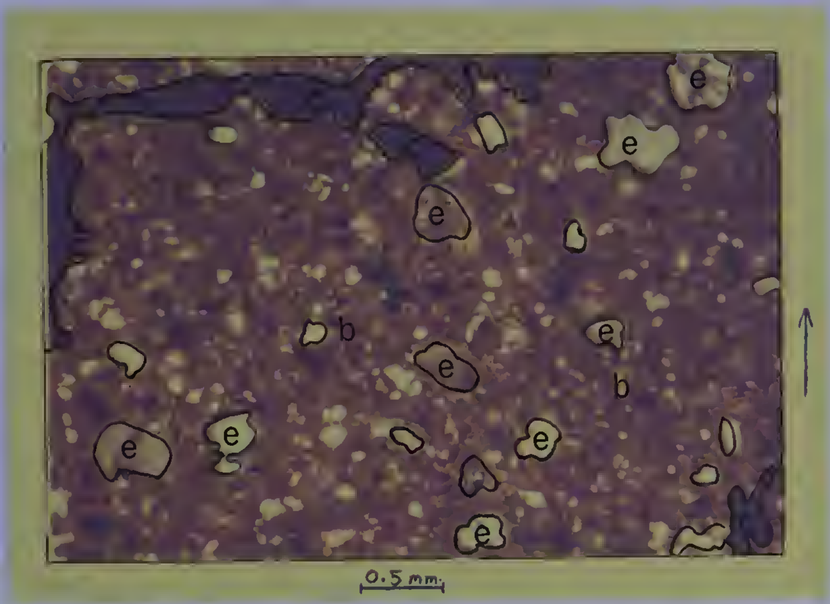


Plate 3 - Photomicrograph of Breton till from Site 10 (Crossed nicols)

Breton till is characterized by a grayish buff colored plasma in which skeletal grains are randomly distributed. The relatively high silt content is reflected in the somewhat dull colors illustrated in this photomicrograph. Skeletal grains are poorly sorted, subangular to angular, and consist mainly of quartz, rock fragments, cherts and primary carbonates, in that order. In general, the plasma is essentially uniform, showing very little segregation. Only occassional, weakly oriented skeletal coatings can be observed. Void percentage is estimated to be approximately 5 to 10 per cent.

LEGEND (examples of:)

e Skeletal Grains b Plasma c Voids

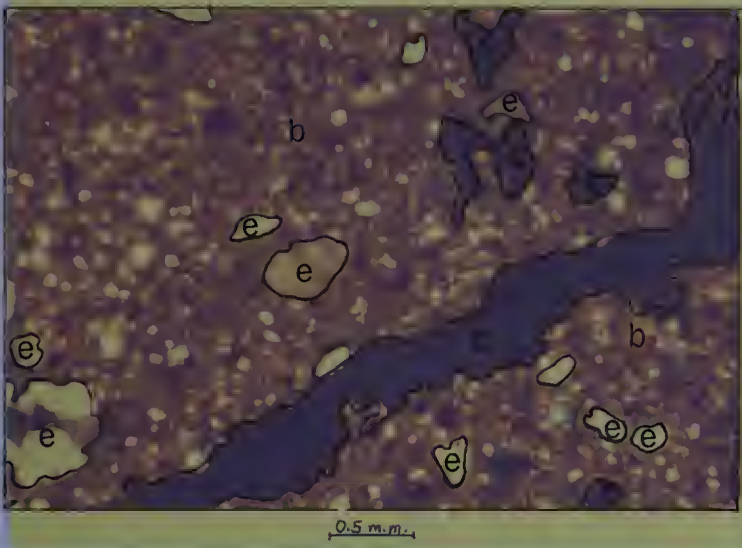


Plate 4 - Photomicrograph of Lobley till from Site 13 (Crossed nicols)

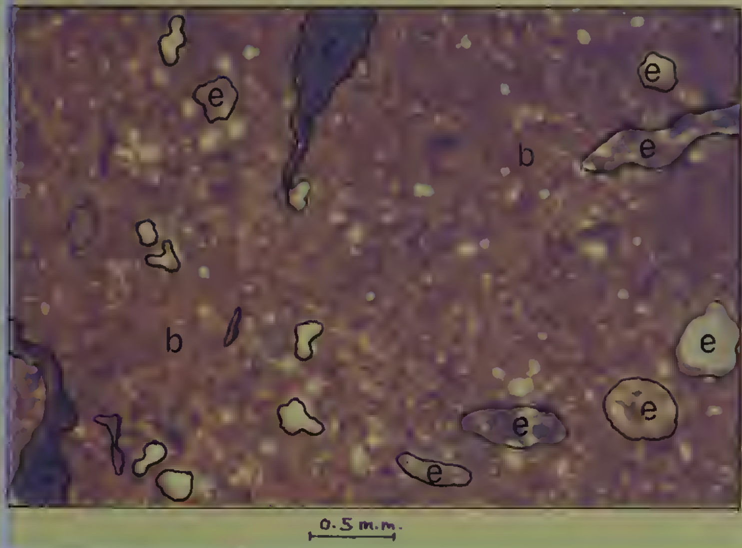
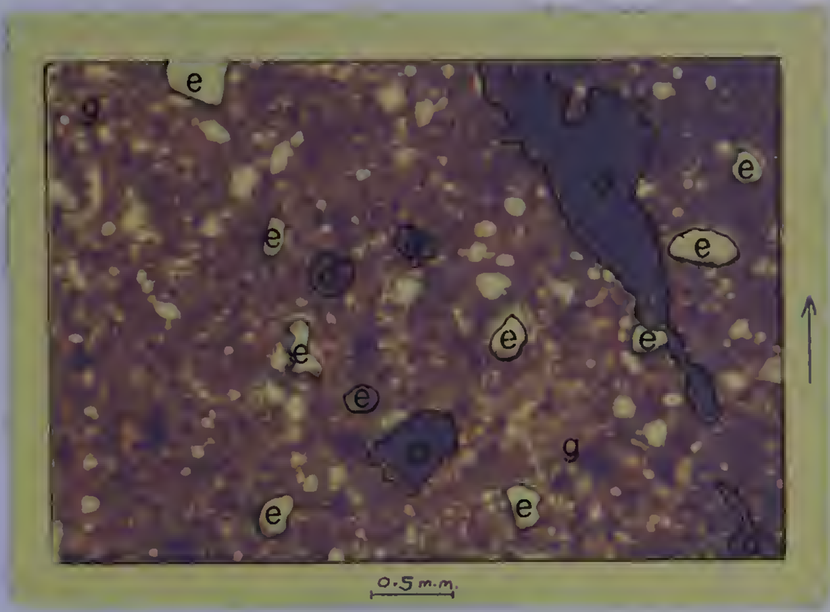


Plate 5 - Photomicrograph of Lobley till from Site 14 (Crossed nicols)

Plates 4 and 5 indicate the variablity in particle size composition which is commonly encountered in Lobley till. In general the plasma of this till varies in color from light brown to buff; it is closely packed and weakly aggregated into moderately friable complexes. This micro-aggregation may be due to the relatively high lime content. Plate 5 illustrates zones of lime concentration between the two voids (arrow), which imparts a reddish coloration to the thin section.

The skeleton is poorly sorted, subangular to angular and randomly distributed. It is generally made up of quartz, rock fragments (sandstones, shales and quartzites), cherts, and primary carbonates. Apart from shale fragments and primary carbonates, most skeletal grains appear to be relatively unweathered. Void percentage is estimated to be 10 to 20 per cent.



LEGEND (examples of:)

e Skeletal Grains

g Plasma

d Voids

Plate 6 - Photomicrograph of Hubalta till from Site 19 (Crossed nicols)

This photomicrograph illustrates the high clay percentage which is characteristic of Hubalta till. This is reflected in the light brown colored plasma and the dense, closely packed matrix. Skeletal coatings, composed of weakly oriented clay minerals, are more common in this till than in the other tills studied.

Skeletal grains are poorly sorted, subangular to angular and randomly distributed. The more common skeletal grains are quartz, rock fragments, cherts, and primary carbonates. Voids constitute approximately 10 per cent of the total matrix.

other than plasma separations."

Examination of the prepared thin sections generally revealed characteristics which are in agreement with the analytical data on the samples. The relatively high percentage of sand and very coarse and coarse sand separates in the Cooking Lake till is illustrated in Plate 2.

The similarity in fabric of the Hubalta and Breton tills is illustrated in the photomicrographs of the tills (Plate 3 and 6). A dense matrix with similar sized, randomly distributed skeletal material is portrayed. Skeletal coatings, composed of weakly oriented clay minerals are found in both tills, however orientation is more pronounced in the Hubalta till. The somewhat browner color in the Hubalta till and duller color in the Breton till photomicrographs, reflects the higher clay and silt content, respectively.

Plates 4 and 5 illustrate the variability commonly found in the Lobley till. The till sample illustrated in plate 4 has a coarser texture than that found in the till sample illustrated in plate 5.

The matrix appears to vary from dense to somewhat loose, but the skeletal material is generally randomly distributed throughout. The high lime content in the Lobley till is reflected by the micro-aggregation of the plasma. Lime concentration, commonly found in the till, is portrayed in Plate 5 by the reddish coloration near the voids.

In summary no single analysis will differentiate the 4 tills under study although groups of analyses indicate that the tills can be differentiated.

Significant differences occurred the following number of

times for various analyses, according to Duncan's new multiple range test at 95 per cent confidence limits:

Reference Till Groups	Physical Analyses	Chemical Analyses	Mineralogical Analyses	Total
Lobley-Hubalta	13	3	11	27
Lobley-Cooking Lake	13	3	11	27
Lobley-Breton	12	2	12	26
Cooking Lake-Breton	9	2	12	23
Cooking Lake-Hubalta	13	2	6	21
Hubalta-Breton	3	1	3	7
	63	13	55	131

The data in the above table suggests that there are significant differences in the 4 groups of till studied. The Hubalta and Breton tills can only be differentiated on the basis of 7 properties out of a total of 58 analyses run through the computer. There is no significant difference between the Hubalta and Breton tills for 51 independent analyses thus suggesting a great deal of similarity between these 2 tills. Physical and mineralogical analyses appear to be more effective than chemical analyses for differentiating among the Lobley, Breton, Hubalta and Cooking Lake tills.

In many respects the 4 till groups are somewhat similar. Texturally they may be classified as loams and clay loams, although slight but significant differences in texture occur. The fine and very fine sand separates comprise the majority of the total sand in the 4 tills. There is no significant difference in real specific gravity, per cent light and heavy minerals (S.G. = 2.96), sandstone, dolomite

and quartzite content and dithionate extractable iron and aluminum. Ninety-five per cent of the coarse fragment distribution is less than 8 mm. in size, suggesting that the 4 tills are derived mainly from soft underlying bedrock. Low amounts of water soluble salts in the tills, indicates that they are non-saline. The clay mineralogy is similar with montmorillonite and illite being the major clays present in the 4 groups of till. Although the type of expansible-clay mineral in the Lobley till likely differs from the others.

The Lobley till, because it is derived from the Cordilleran region can be easily characterized. It was found to have the following properties which distinguish it from the 3 Continental tills:

1. Generally void of igneous and metamorphic crystalline pebbles.
2. A limestone content of 37 per cent as compared to about 9 per cent in the Continental tills.
3. A calcium carbonate equivalent of 10.4 per cent as compared to 3.7 per cent for the Continental tills.
4. The iron concretion content is less than 1 per cent whereas for Continental tills it averages 6.7 per cent.
5. A 28 per cent illite content as compared to 21 per cent in the Continental tills.
6. The montmorillonite content is 45 per cent as compared to 53 per cent in the Continental tills.
7. The coarse fragment content (2 - 4 mm.) is 75.6 per cent in the Lobley till and 86.3 per cent in the Continental tills.
8. The total opaque and zircon contents of the Lobley till are 73.3 and 2.3 per cent respectively, whereas in the Continental tills these heavy minerals amount to 46.0 and 0.9 per cent.
9. Generally void of amphiboles and pyroxenes.
10. An average garnet content of 3.8 per cent as compared to 10.0 per cent for the Continental tills.
11. Generally contains a higher percentage of pebbles.

The Lobley till is generally the most variable of the 4 tills studied as indicated by the larger standard deviation for most analyses.

The Cooking Lake till can be distinguished from the Hubalta and Breton tills by the following characteristics:

1. The total sand content of the 3 tills is - Cooking Lake 42 per cent, Hubalta 30 per cent and Breton 38 per cent.

2. A coarse sand content of 15, 9, and 8 per cent, respectively for the Cooking Lake, Hubalta, and Breton tills.
3. The bulk density of the 3 tills is - Cooking Lake 1.61 g./c.c., Hubalta 1.47 g./c.c., and Breton 1.54 g./c.c..
4. A coarse fragment content (4 - 8 mm.) of 6.4, 14.2, and 13.0 per cent, respectively for the Cooking Lake, Hubalta, and Breton tills.
5. A quartz content in the Cooking Lake till fine sand fraction (S.G.$<$ 2.96) of 80 per cent as compared to 72 per cent in the Hubalta till and 70 per cent in the Breton till.
6. An epidote content in the Cooking Lake till fine sand fraction (S.G.$>$2.96) of 3.4 per cent as compared to 6.4 and 7.0 per cent in the Hubalta and Breton tills, respectively.
7. An amphibole content in the Cooking Lake till fine sand fraction (S.G.$>$2.96) of 27.6 per cent as compared to 13.0 and 10.8 per cent in the Hubalta and Breton tills, respectively.

The Cooking Lake till generally is characterized by numerous sand pockets and lenses which are generally absent in the Hubalta and Breton tills (This is typical of hummocky ground moraine or ablation till regardless of region).

The Hubalta and Breton tills are very similar. They can best be differentiated by texture. The Hubalta till is finer textured, containing a significantly higher percentage of total clay and fine clay than the Breton till. The Breton till contains a significantly higher percentage of montmorillonite than the Hubalta till as determined by surface area and cation exchange capacity on separated total clay samples.

The color of the Breton till is generally a dark yellowish brown to a light olive brown (moist) while the Hubalta till is generally a olive brown (moist). The Breton till is somewhat yellower than the Hubalta till, although the colors of all 4 tills are somewhat similar.

Part B - Till Samples from the Chip Lake map and Adjacent Areas in west-central Alberta

On the basis of field characteristics 2 groups of till were established in the map area, one which was thought to be reasonably similar to the Hubalta till and the other a Hubalta-Breton intergrade till. The Hubalta till group from the Chip Lake map area is represented by 11 samples from sites 24, 25, 26, 27, 31, 34, 36, 38, 41, 42 and 43. The Hubalta-Breton intergrade till group, from the Chip Lake map area is represented by 7 samples from sites, 28, 29, 32, 35, 37, 39 and 40.

The similarity of the 2 groups of till to the 4 reference till groups described previously were tested with the aid of a computer. The means and standard deviations for various analyses of the tills from the Chip Lake map area are reported in Table 21, 21A, 24 and 25. The individual sample results comprising the 2 groups of till are reported in Appendix B, Tables XIIc to XXc. Significant differences between the 6 groups of till, in decreasing order of significance, as determined by "Duncan's" new multiple range test, for various analyses are shown in Tables 22, 23 and 26. The range test was carried out at 95 per cent confidence limits and thus an F value greater than 2.49 was required for all analyses, except the $CaCO_3$ equivalent analysis, in order to show a significant difference. (The $CaCO_3$ equivalent analysis was conducted on 8 samples only, in the Hubalta till group from the Chip Lake map area, and an F value greater than 2.52 was required.)

The X-ray diffractograms and differential thermographs for the clay fractions separated from the till samples are shown in Appendix B, Figures IIc to IXc.

TABLE 21 - The Means and Standard Deviations for the Physical Analyses of the Hubalta and Hubalta-Breton Intergrade Till Groups from the Chip Lake map area

Sample Group	# of rep's.	Sand (%)	Silt (%)	Clay (%)	Fine Clay (%)	Sand Separates* V.C.S. (%)	C.S. (%)	M.S. (%)	F.S. (%)	V.F.S. (%)
Hubalta	11	31.7±3.8	34.8±2.7	33.4±3.1	17.0±2.0	2.6±1.0	10.9±2.5	15.9±1.5	40.7±2.7	29.7±2.8
Hub.-Bn. intergrade	7	29.7±7.8	37.5±5.1	32.7±3.9	15.6±2.3	1.7±0.7	8.5±2.4	14.3±1.9	43.4±1.5	31.9±4.0

Sample Group	# of rep's.	Bulk Density (g./c.c.)	Penetrometer values (tons/ft.^{2})	Depth of Profile (inches)	Real Specific Gravity
Hubalta	11	1.49±0.06	1.88±0.96	55.3±13.2	2.59±0.02
Hub.-Bn. intergrade	7	1.47±0.12	1.86±0.96	48.1±7.8	2.59±0.02

Sample Group	# of rep's.	Pebble Composition Limestones (%)**	Sandstones (%)**	Dolomites (%)**	Quartzites (%)**	Granites (%)**	Others○ (%)**	Sandstones + Quartzites (%)**
Hubalta	11	3.5±3.96	17.7±9.4	0.37±0.54	44.5±12.8	17.1±5.8	16.9±3.3	62.1±10.4
Hub.-Bn. intergrade	7	6.4±7.7	26.9±17.4	0.90±1.44	42.0±20.7	9.9±2.7	13.8±5.1	68.9±5.2

Sample Group	# of rep's.	Coarse Fragment Distribution < 32mm.** >16mm.(%)	<16mm.** >8mm.(%)	<8mm.** >4mm.(%)	<4mm.** >2mm.(%)
Hubalta	11	0.43±0.57	2.71±1.55	14.65±6.58	82.0±8.6
Hub.-Bn. intergrade	7	0.80±0.98	3.51±1.70	18.06±7.82	77.3±9.3

* Based on summation of sand fraction
** Per cent by number
○ For composition see Table 21A

TABLE 21A - Pebble Composition of those Classified as "Others" in Table 21*

Sample Number	Iron Concretions (%)	Crystalline** Metamorphic (%)	Siltstones (%)	Others*** (%)	Igneous + Metamorphic Crystalline**** (%)
Hubalta Till from the Chip Lake map area					
24	4.9	3.9	-	3.3	14.5
25	2.7	8.9	-	5.4	28.6
26	4.9	2.8	-	5.7	11.6
27	7.4	4.0	0.8	7.6	16.2
31	4.0	9.1	-	8.0	23.7
34	6.2	11.9	-	3.8	35.3
36	7.2	4.4	-	4.1	24.2
38	6.4	4.4	0.7	3.6	21.6
41	5.1	4.4	0.4	5.3	20.5
42	4.1	5.8	-	4.5	20.5
43	14.3	3.1	-	2.8	32.0
Mean and S.D.	6.11±3.07	5.7±2.9	0.17±0.31		22.6±7.3
Hub.-Bn. Till intergrade from the C.L. map area					
28	7.7	3.9	-	7.6	12.6
29	10.1	5.6	-	4.7	17.1
32	3.4	3.4	-	4.1	15.5
35	7.4	5.1	-	4.6	16.3
37	3.0	4.4	-	3.0	16.3
39	1.3	2.4	-	2.9	12.2
40	3.7	5.5	-	3.0	9.9
Mean and S.D.	5.23±3.18	4.3±1.2	-		14.3±2.7
Till from the Chip Lake and adjacent areas					
23	5.2	6.5	1.9	7.7	25.7
30	5.2	7.8	-	9.1	21.3
33	3.5	1.5	-	5.6	16.3
44	2.8	0.3	31.4	0.3	2.8
45	-	-	2.5	1.6	-
46	-	0.3	2.9	45.0 ●	0.3

* Based on summation of total pebbles counted
** Comprised mainly of gneiss and schist
*** Comprised mainly of chert, flint, coal, and quartz
**** Comprised mainly of granite, gneiss, and schist
● Entrance Conglomerate comprises 40 per cent

TABLE 22 - Significant Differences as Determined by Duncan's New Multiple Range Test for the Hubalta and Hubalta-Breton Intergrade Till Groups from the Chip Lake map area and the Reference Till Groups

Physical Analyses*

				Sand Separates					
Sand (%)	Silt (%)	Clay (%)	Fine Clay (%)	V.C.S. (%)	C.S. (%)	M.S. (%)	F.S. (%)	V.F.S. (%)	Depth of Profile (inches)
Ck.-Lob.	Lob.-Ck.	(A)-Bn.	(A)-Bn.	Ck.-(B)	Ck.-Lob.		(B)-Ck.	Lob.-Ck.	Bn.-Lob.
Ck.-(B)	Lob.-(A)	(A)-Ck.	(A)-Lob.	Ck.-Hub.	Ck.-Bn.	No	Hub.-Ck.	Lob.-(A)	(A)-Lob.
Ck.-Hub.	Lob.-Hub.	Hub.-Bn.	Hub.-Bn.	Ck.-Bn.	Ck.-(B)	Difference	(B)-Lob.	Lob.-Hub.	Bn.-Ck.
Ck.-(A)	Lob.-(B)	Hub.-Ck.	Hub.-Lob.	Ck.-(A)	Ck.-Hub.		Hub.-Lob.	Lob.-(B)	(A)-Ck.
Bn.-Lob.	Lob.-Bn.	(B)-Bn.	(A)-Ck.	Lob.-(B)	Ck.-(A)		Bn.-Ck.	Bn.-Ck.	Hub.-Lob.
Bn.-(B)	Bn.-(A)	(B)-Ck.	(B)-Bn.	Lob.-Hub.	(A)-Lob.		Bn.-Lob.	(B)-Ck.	(B)-Lob.
Bn.-Hub.		Lob.-Bn.	(B)-Lob.	Lob.-Bn.				Hub.-Ck.	Hub.-Ck.
Bn.-(A)		Lob.-Ck.	Hub.-Ck.	Lob.-(A)				Lob.-Bn.	(B)-Ck.
		(A)-Lob.	(B)-Ck.						
F=8.74	F=5.65	F=11.21	F=14.21	F=8.25	F=7.93	F=2.38	F=4.75	F=4.75	F=6.67

			Pebble Composition						
Penetrometer values (tons/ft.^{2})	Bulk Density (g./cc.)	R.S.G	Limestones (%)	Sandstones (%)	Dolomites (%)	Quartzites (%)	Granites (%)	Others (%)**	Quartzites+ Sandstones (%)
Ck.-(B)	Ck.-Hub.		Lob.-(A)				Lob.-(A)	Bn.-Lob.	(B)-Lob.
Ck.-Hub.	Ck.-(B)	No	Lob.-Bn.	No	No	No	Lob.-Hub.	Ck.-Lob.	Bn.-Lob.
Ck.-(A)	Ck.-(A)	Difference	Lob.-(B)	Difference	Difference	Difference	Lob.-Ck.	Hub.-Lob.	(A)-Lob.
Ck.-Lob.	Lob.-Hub.		Lob.-Hub.				Lob.-(B)	(A)-Lob.	Hub.-Lob.
Ck.-Bn.			Lob.-Ck.				Lob.-Bn.	Bn.-(B)	(B)-Ck.
							(A)-Bn.	Ck.-(B)	
							(A)-(B)	(B)-Lob.	
F=4.45	F=3.26	F=2.46	F=14.67	F=0.78	F=1.67	F=1.53	F=9.76	F=6.66	F=5.07

* Ranked according to decreasing levels of significance at 95 per cent confidence limits
** For Composition see Table 21A

Ck. Cooking Lake Till group
Bn. Breton Till group
Lob. Lobley Till group
Hub. Hubalta Till group

(A) Hubalta Till group from the Chip Lake map area
(B) Hubalta-Breton intergrade Till group from the Chip Lake map area
F value must be greater than 2.49 inorder for significant differences to occur, between the 6 Till groups (95% C.L.)

TABLE 23 - Significant Differences as Determined by Duncan's New Multiple Range Test for the Hubalta and Hubalta-Breton Intergrade Till Groups from the Chip Lake map area and the Reference Till Groups

Physical Analyses*

Coarse Fragment Distribution			
<32mm. >16mm. (%)	<16mm. >8mm. (%)	<8mm. >4mm. (%)	<4mm. >2mm. (%)
No Difference	Lob.-Ck.	Lob.-Ck.	Ck.-Lob.
	Lob.-Bn.	(B)-Ck.	Ck.-(B)
	Lob.-(A)	(A)-Ck.	Ck.-(A)
	(B)-Ck.	Hub.-Ck.	Ck.-Hub.
	Lob.-Hub.		
F=1.20	F=3.44	F=3.15	F=3.39

Chemical Analyses*

$CaCO_3$** (%)	C.E.C. (me./100g.)	Fe (%)	Al (%)	Fe + Al (%)	Electrical Conductivity (mmhos/cm.^{2})	Soluble Salts (me./litre) Na^+	K^+	Mg^{++}	Ca^{++}
Lob.-Hub.	Hub.-Ck.	No Significant Difference among the 6 Till groups			Ck.-(A)	Ck.-(B)	No Significant Difference among the 6 Till groups		
Lob.-(A)	(B)-Ck.				Ck.-Lob.	Ck.-Lob.			
Lob.-Bn.	(A)-Ck.				Ck.-Bn.	Ck.-(A)			
Lob.-Ck.	Bn.-Ck.				Ck.-(B)	Ck.-Hub.			
Lob.-(B)	Hub.-Lob.				Ck.-Hub.				
	(B)-Lob.								
	(A)-Lob.								
	Bn.-Lob.								
	Lob.-Ck.								
F=15.09	F=12.23	F=1.91	F=0.36	F=1.96	F=2.74	F=2.60	F=0.58	F=2.40	F=1.28

* Ranked according to decreasing levels of significance at 95 per cent confidence limits
F value must be greater than 2.49 in order for significant differences to occur, between the 6 Till groups

** F value must be greater than 2.52 in order for significant differences to occur, between the 6 Till groups

Ck. Cooking Lake Till group
Bn. Breton Till group
Lob. Lobley Till group
Hub. Hubalta Till group
(A) Hubalta Till group from the Chip Lake map area
(B) Hubalta-Breton intergrade Till group from the Chip Lake map area

TABLE 24 - The Means and Standard Deviations for the Chemical Analyses of the Hubalta and Hubalta-Breton Intergrade Till Groups from the Chip Lake map area

Sample Group	# of rep's.	$CaCO_3$ (%)	C.E.C. (me./100g.)	Fe (%)	Al (%)	Fe + Al (%)
Hubalta	11	3.49±0.81*	19.6±1.3	0.85±0.19	0.12±0.08	0.98±0.21
Hubalta-Breton intergrade	7	4.91±1.79	20.2±2.6	0.76±0.04	0.12±0.10	0.88±0.10

			Soluble Salts (me./litre)			
Sample Group	# of rep's.	Electrical Conductivity (mmhos/cm².)	Na^+	K^+	Mg^{++}	Ca^{++}
Hubalta	11	0.26±0.07	1.11±0.33	0.08±0.04	0.95±0.23	7.01±1.60
Hubalta-Breton intergrade	7	0.29±0.12	1.19±0.49	0.06±0.02	0.98±0.16	7.70±1.90

* Based on 8 samples instead of 11

TABLE 25 - The Means and Standard Deviations for the Mineralogical Analyses of the Hubalta and Hubalta-Breton Intergrade Till Groups from the Chip Lake map area

Clay Mineralogy

Sample Group	# of rep's.	C.E.C. (me./100g.)	Surface Area ($m.^2/g.$)	K_2O (%)	% Montmorillonite (1)	% Montmorillonite (2)	% Montmorillonite (mean)
Hubalta	11	49.2±5.4	514.6±56.6	2.18±0.34	50.1±6.2	51.1±5.6	50.6±5.6
Hubalta-Breton intergrade	7	52.8±3.1	526.1±39.7	2.08±0.27	54.1±3.6	52.4±4.0	53.4±3.6

(1) Montmorillonite based on cation exchange capacity data
(2) Montmorillonite based on surface area data

Fine Sand Mineralogy (0.114mm.-0.25mm.)

Sample Group	# of rep's.	Light Mineral Analysis (S.G. $<$ 2.96) K Feldspar (%)	Soda-Calcic Feldspar (%)	Total Feldspar (%)	Quartz* (%)	Light and Heavy Mineral Distribution Light Minerals (S.G. $<$ 2.96) (%)	Heavy Minerals (S.G. $>$ 2.96) (%)
Hubalta	11	8.1±2.0	18.1±4.9	26.2±6.7	73.8±6.7	99.03±0.24	0.97±0.23
Hubalta-Breton intergrade	7	8.6±1.9	19.9±4.0	28.4±5.7	71.6±5.7	99.22±0.18	0.78±0.11

* Determined by difference

TABLE 26 - Significant Differences as Determined by Duncan's Multiple Range Test for the Hubalta and Hubalta-Breton Intergrade Till Groups from the Chip Lake map area and the Reference Till Groups

Clay Mineralogy*

C.E.C. (me./100g.)	Surface Area ($m.^2/g.$)	K_2O (%)	% Montmorillonite (1)	% Montmorillonite (2)	% Montmorillonite (mean)
Bn.-Ck.	Bn.-Lob.	Lob.-Ck.	Bn.-Ck.	Bn.-Lob.	Bn.-Lob.
Bn.-Lob.	Hub.-Lob.	Lob.-Bn.	Bn.-Lob.	Hub.-Lob.	(B)-Lob.
Bn.-(A)	(B)-Lob.	Lob.-(A)	Bn.-(A)	(B)-Lob.	Hub.-Lob.
Bn.-Hub.	(A)-Lob.	Lob.-(B)	Bn.-Hub.	(A)-Lob.	Bn.-Ck.
	Ck.-Lob.	Lob.-Hub.		Ck.-Lob.	Bn.-(A)
					(A)-Lob.
F=3.21	F=7.04	F=3.10	F=2.98	F=7.25	F=4.84

(1) Montmorillonite based on cation exchange capacity data

(2) Montmorillonite based on surface area data

Fine Sand Mineralogy (0.114mm.-0.25mm.)*

Light Mineral Analysis (S.G.<2.96)				Light and Heavy Mineral Distribution	
K Feldspar (%)	Soda-Calcic Feldspar (%)	Total Feldspar (%)	Quartz (%)	Light Minerals (S.G.<2.96) (%)	Heavy Minerals (S.G.>2.96) (%)
No Significant Difference	No Significant Difference	No Significant Difference	No Significant Difference	No Significant Difference	No Significant Difference
F=1.99**	F=1.87	F=1.99	F=1.99	F=0.26	F=1.93

* Ranked according to decreasing levels of significance at 95 per cent confidence limits

F value must be greater than 2.49 in order for significant differences to occur, between the 6 Till groups

(A) Hubalta Till from the Chip Lake map area

(B) Hubalta-Breton intergrade,Till group from the Chip Lake map area

Ck. - Cooking Lake Till group

Bn. - Breton Till group

Lob. - Lobley Till group

Hub. - Hubalta Till group

TABLE 27 - Significant Differences for the Groups of Till as Determined by Duncan's New Multiple Range Test for Various Analyses

Till Group Combinations	Physical Analyses	Chemical Analyses	Mineralogical Analyses	Total
Lob.-Ck.	12	4	3	19
Lob.-Bn.	12	2	6	20
Lob.-Hub.	12	2	4	18
Lob.-(A)	12	2	4	18
Lob.-(B)	10	2	4	16
Ck.-Bn.	6	2	3	11
Ck.-Hub.	12	3	-	15
Ck.-(A)	10	3	-	13
Ck.-(B)	15	3	-	18
Bn.-Hub.	3	-	2	5
Bn.-(A)	5	-	3	8
Bn.-(B)	4	-	-	4
Hub.-(A)	-	-	-	0
Hub.-(B)	-	-	-	0
(A)-(B)	1	-	-	1
Total	114	23	29	166

Lob. -Lobley reference till group
Ck. -Cooking Lake reference till group
Bn. -Breton reference till group
Hub. -Hubalta reference till group
(A) -Hubalta till group from the Chip Lake map area
(B) -Hubalta-Breton intergrade till group from the Chip Lake map area

TABLE 28 - The Distribution of some of the Heavy Minerals in the Till Samples from the Chip Lake map and Adjacent areas (S.G.$>$2.96)

Sample Number	Total Opaques* (%)	Amphiboles* (%)	Zircons* (%)	Garnets* (%)	Others* (%)
23	55.5	13.5	0.2	10.4	20.4
30	75.1	3.9	0.0	3.4	17.6
33	32.6	21.6	0.2	8.5	37.1
44	49.3	11.3	0.4	8.9	29.1
45	48.0	T	7.0	14.0	31.0
46	62.0	0.0	3.0	3.7	31.3

T - Trace (less than 1 per cent)

* - All values expressed as per cent of total mineral grains counted (minimum of 300 grains)

Others - includes epidote, pyroxene, staurolite, zoisite, clinozoisite, biotite, chlorite, andalusite, rutile, monazite, apatite, tourmaline, kyanite, sillimanite, and unidentified

Since it is impossible to differentiate between the heavy mineral suites in the Hubalta and Breton tills the analysis was not carried out in detail. However, a cursory examination of some slides indicated that the mineral suites of the Hubalta and Hubalta-Breton intergrade till groups from the Chip Lake map area were similar to both the Hubalta and Breton till samples.

The Hubalta and Hubalta-Breton till intergrade groups from the Chip Lake map area have the following properties that differentiate them from the Lobley till:

1. A higher average fine clay content of 17.0 and 15.6 per cent, respectively.
2. A lower average limestone content of 3.5 and 6.4 per cent, respectively.
3. A higher average igneous and metamorphic crystalline pebble content of 22.6 and 14.3 per cent, respectively.
4. A higher average iron concretion content of 6.1 and 5.2 per cent, respectively.
5. A lower average $CaCO_3$ equivalent of 3.49 and 4.91 per cent, respectively.
6. A lower average illite content of 22 and 21 per cent, respectively.
7. A higher average expansible clay mineral content of 50.6 and 53.4 per cent, respectively.

The Hubalta and Hubalta-Breton intergrade till groups from the Chip Lake map area can be readily differentiated from the Lobley till group on the basis of at least 16 physical, chemical and mineralogical properties (Table 27).

The 2 major groups from the Chip Lake map area may be readily distinguished from the Cooking Lake till (Table 27). Some of the most significant differentiating criteria are:

1. A lower average sand content of 31.7 and 29.7 per cent, respectively for the Hubalta and Hubalta-Breton intergrade till groups.
2. A lower average coarse sand content of 10.9 and 8.5 per cent, respectively.
3. A lower average bulk density of 1.49 and 1.47 g./c.c., respectively.
4. A higher average coarse fragment content in the 4-8 m.m. fraction of 14.6 and 18.1 per cent, respectively.
5. A lower average electrical conductivity of 0.26 and 0.29 mmhos/cm.^{2}, respectively.
6. A higher average total clay content of 33.4 and 32.7 per cent, respectively.
7. A more deeply developed soil profile of 55.3 and 48.1 inches, respectively.
8. A higher average cation exchange capacity of 19.6 and 20.2 me./100 g., respectively.

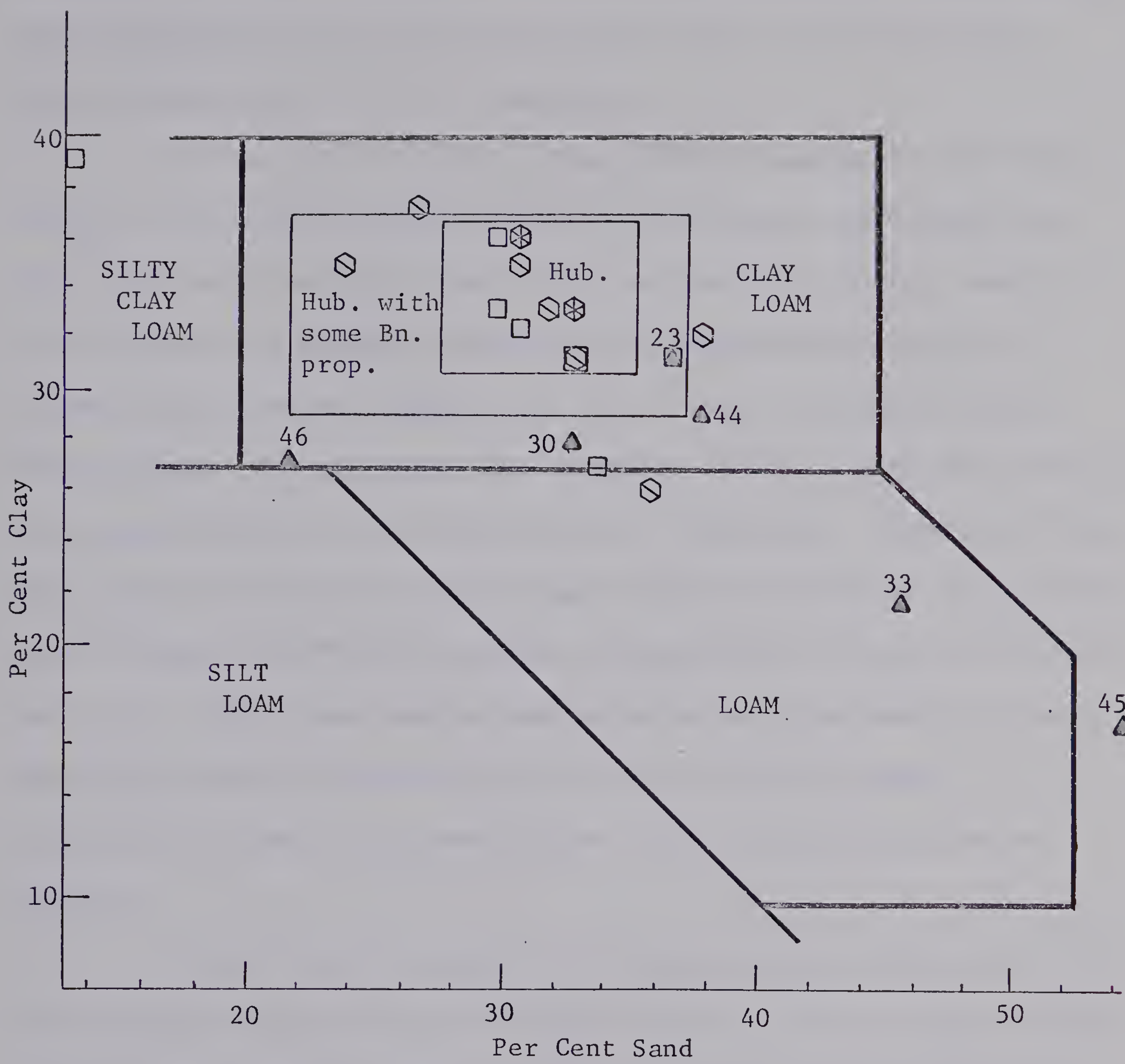
From a total of 46 independent analyses conducted on the 6 groups of till; of the representative Breton and Hubalta tills only 5 properties were found to be significantly different. The representative Breton till group and the Hubalta till group from the Chip Lake map area could be differentiated on the basis of 8 characteristics; while for the representative Breton and Hubalta-Breton intergrade till groups, only 4 characteristics were found to be significantly different. These

differences are mainly texture and average percent montmorillonite in the clay fractions. The Hubalta till is finer textured than the Breton till and the Breton till contains a significantly higher percentage of montmorillonite. However the average per cent montmorillonite in the Hubalta-Breton intergrade till group is similar to the representative Breton till group.

The investigated properties of the Hubalta and Hubalta-Breton intergrade till groups from the Chip Lake map area were found to be statistically not significantly different from the representative Hubalta till group. It is noted however, that in comparing the 2 till groups from the Chip Lake map area (which were selected randomly) a significant difference was found with respect to only one property, that is in the granite pebble content.

In summary the 2 till groups from the Chip Lake map area were found to be similar to the Hubalta till. The Hubalta-Breton intergrade till group does have some characteristics in common with the Breton till group. However on the basis of the present range of variability found in the characteristics of the established tills the separation of this group into a new soil Series is not warranted. The characteristics of the 2 groups of till from the Chip Lake map area are generally more variable than those characteristics found in the representative tills (Figure 21). This is to be expected since only the modal type of till samples were selected for the representative samples, while samples collected in the Chip Lake map area generally were selected at random.

The remaining 6 samples could not be categorized with the aid of a computer because of wide discrepancies in their field characteristics. These tills consist of samples from sites 23, 30, 33,



Legend: ⊘ Hubalta till samples from the Chip Lake map area.
□ Hubalta till samples with some Breton till characteristics from the Chip Lake map area.
23 △ Till samples from the Chip Lake map and adjacent areas. Number indicates till sample number.

Figure 21 - Particle Size Distribution of the Tills from the Chip Lake map and Adjacent areas (rectangles indicate the standard deviation from the mean)

44, 45 and 46. The various analyses for the 6 samples are shown in Tables XIIc to XXc of Appendix B. The X-ray diffractograms and differential thermographs of the calcium saturated total clay fractions are shown in Figures IIc to IXc of Appendix B.

On the basis of field characteristics samples 23 and 30 were thought to be morphologically similar to the Hubalta and Cooking Lake tills. The relatively high total clay and fine clay content, depth of the overlying soil profile, low electrical conductivity values, and low penetrometer values suggest that the 2 tills are similar to the Hubalta group. The relatively low amphibole content in the heavy minerals also suggests Hubalta till characteristics (Table 28). However the high very coarse and coarse sand percentage, low cation exchange capacity and coarse fragment distribution suggests characteristics similar to Cooking Lake till. Since these samples were selected near the boundary between the Cooking Lake and Hubalta tills in the Chip Lake map area, characteristics that intergrade between those of the 2 tills can be expected.

Sample 33 was thought to be similar to the Cooking Lake till. The relatively high percentage of total sand and low percentage of total clay and fine clay lies within the limits established for the Cooking Lake till. Other properties of this sample which lie within the limits of the Cooking Lake till are:

1. Coarse sand percentage of 16.1 per cent.
2. Very fine sand percentage of 22.6 per cent.
3. Cation exchange capacity of 10.5 me./100 grams.
4. Electrical conductivity of 0.40 mmhos/cm.^{2}.
5. An amphibole content in the heavy minerals of 21.6 per cent.

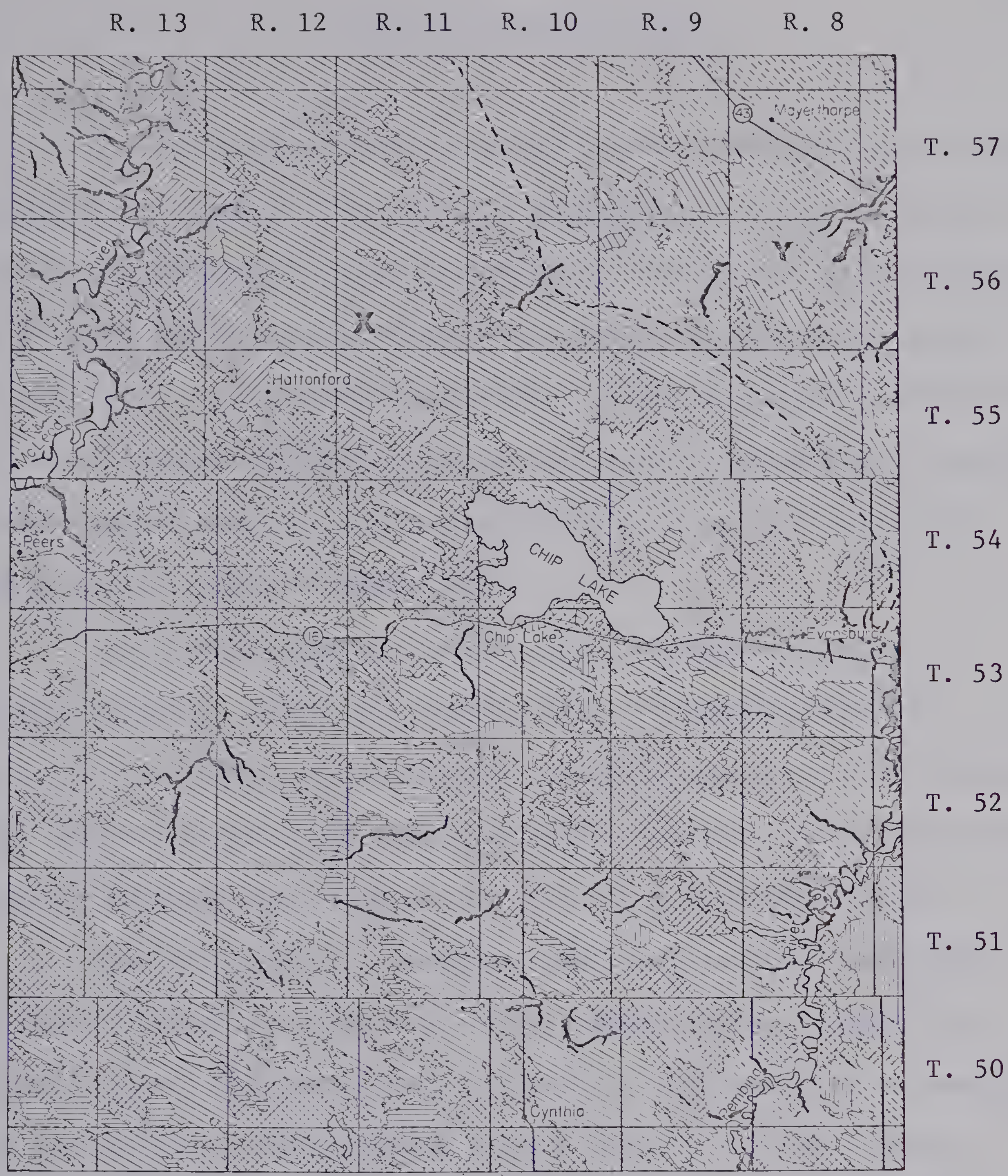
However the coarse fragment distribution, very coarse sand and fine sand percentage as well as the depth of the overlying soil profile suggest characteristics common to Hubalta and Breton till. Generally this sample may be considered an intergrade between Hubalta and Cooking Lake till, with a tendency toward the Cooking Lake till group.

The analytical data for sample 44 suggests that the till sample could be placed with the Breton or Hubalta till groups. However the yellowish brown color, and higher average percent montmorillonite in the clay fraction suggests that sample 44 best fits the Breton till characteristics.

Samples 45 and 46 are likely deposited by the Cordilleran ice sheet since crystalline igneous and metamorphic pebbles are absent. Amphiboles are also absent in the fine sand fraction. The analytical results for sample 45, such as the very coarse sand percentage, bulk density, coarse fragment distribution, cation exchange capacity, depth of the overlying soil profile, calcium carbonate equivalent, and the relative percentage of illite in the clay fraction lie within the established limits of the Lobley till. However large discrepancies from the Lobley till were found for mechanical analysis as well as the percentage of limestones and suggests that this till may be of different lithological composition.

Sample 46 cannot be placed in the Lobley till group because the majority of the results of the analyses are outside the established limits. The high percentage of "Entrance Conglomerate" (Table 21A) and no limestones as well as only a trace amount of inorganic carbonate suggests that this till was derived from bedrock of different lithology than the Lobley till.

The distribution of the tills, in the Chip Lake map area, and their relation to other parent materials are shown in Figure 22. The main till mapped in the area is Hubalta. Tills which are similar to the Cooking Lake and Lobley are found in the northeast corner and extreme southwest corner of the map respectively. Till with characteristics similar to Breton till is found generally, in the southeast corner of the map.



LEGEND

	Organic		Alluvial and Outwash
	Lacustrine		Hubalta Till
	Aeolian Sand		Breton Till
	Paskapoo Formation		Lobley Till
	Alluvium		Cooking Lake Till
X	Paskapoo Bedrock Formation	Y	Edmonton Bedrock Formation

Figure 22 Parent Material Map of the Chip Lake area

V. SUMMARY AND CONCLUSIONS

The investigation of the Lobley, Hubalta, Breton and Cooking Lake glacial till parent materials was undertaken to determine whether or not the separation of the soils developed from these parent materials into different Series is justified on the basis of differences in the lithology, fabric and composition of their parent materials. A further objective of this investigation was to determine if unknown till samples, from west-central Alberta, can be identified with any of the 4 till parent materials under consideration.

The characterization of the tills was carried out by conducting physical, chemical, mineralogical and micropedological analyses. On the basis of the analyses conducted on the Lobley, Hubalta, Cooking Lake and Breton till parent materials there is justification for separating the soils developed on the tills into different Series.

The Lobley till is found on undulating to hilly topography in the lower foothills region near Rocky Mountain House, usually at elevations of over 3500 feet above sea level. The land form is generally ground moraine with the underlying bedrock generally being Paskapoo sandstone. The till is light olive brown to olive brown in color and has a friable consistency.

The Lobley till was deposited from the Cordilleran ice sheet being characterized by a lack of high grade crystalline metamorphic and igneous pebbles. The material is stony, the pebbles being a mixture of smooth waterworn quartzites, soft gray to yellowish gray sandstones and limestones. The limestone content varies from 30 to 46 per cent and reflects a moderately high calcium and magnesium carbonate content.

The relatively high percentage of limestone indicates that a limestone subcrop was overriden by the glacier or glaciers which deposited the Lobley till. Iron concretions are not common in the Lobley till. The majority of the pebbles in the till are smaller than 4 mm. in size. The texture of the Lobley till varies from a silt loam to a clay loam suggesting a large amount of variability within the till. The depth of the overlying soil profile is fairly shallow with lime occuring at 24 to 44 inches; often there are streaks in the lower portion of the profile that are quite high in lime. The till is nonsaline with a electrical conductivity of 0.20 to 0.38 mmhos/cm.[2].

Clay mineralogical analyses for the total clay fraction separated from the Lobley till indicates an illite content of 26 to 32 per cent and an average clay mineral content of 40 to 49 per cent. The expansible clay mineral is expected to be a highly charged montmorillonite species.

Heavy mineral identification of the 0.114 mm. to 0.250 mm. sand fraction, indicates that the Lobley till is characterized by a high percentage of total opaques, essentially no amphiboles and pyroxenes, and a low garnet content.

The Cooking Lake till is found on gently rolling to hilly topography in the hummocky dead ice moraine east of Edmonton at elevations below 2600 feet above sea level. It was deposited by the Continental ice sheet and is underlain mainly by the Edmonton Formation. The till is dark grayish brown in color with a firm consistency. Iron stains and sand lenses and pockets are common. Texturally the Cooking Lake till is a loam, with an average sand content of 42 per cent. Of the sand fraction, approximately 20 per cent of the particles are of the

coarse and very coarse sand fractions.

The majority of the pebbles in the Cooking Lake till are less than 4 mm. in size, suggesting that the till is mainly derived from the soft underlying bedrock. The material is stone poor to moderately stony, the pebbles being a mixture of quartzites, limestones, granites, iron concretions and hard sandstones which may be intermediate between the quartzites and soft sandstones. Crystalline igneous and metamorphic pebbles, which consist mainly of granites, gneiss and schists, constitute 15 to 32 per cent of the total pebbles in the till.

The Cooking Lake till is characterized by a low cation exchange capacity, a calcium carbonate equivalent of less than 5 per cent, a relatively shallow overlying soil profile, a high bulk density, and an electrical conductivity of 0.35 to 0.50 mmhos/cm.^{2}, indicating that the till is nonsaline.

The major clay minerals present in the clay fraction of the Cooking Lake till are montmorillonite, illite and interlayered montmorillonite-illite. Trace to minor amounts of kaolinite and chlorite are present. The majority of the light minerals (S.G.$<$2.96) of the fine sand fraction are comprised of quartz. The feldspar content varies from 17 to 26 per cent; the plagioclase series being the dominant feldspar present. Approximately 28 per cent of the heavy minerals (S.G.$>$2.96) are amphiboles in the Cooking Lake till with a range of 21 to 41 per cent. The majority of the other minerals identified are magnetite, hematite, limonite, garnet, epidote and pyroxene.

It was found difficult to interpet the results from the Cooking Lake till samples because of mode of deposition. The samples were taken from a hummocky dead ice moraine, although the till does

occur as undulating ground moraine as well. It is recognized that many of the determined characteristics may be influenced by the mode of deposition as well as the lithological origin. However on the basis of the samples collected in the dead ice moraine, the Cooking Lake till was found to be significantly different from the other 3 tills studied.

The Breton till is found on ground moraine, characterized by undulating to rolling topography. The underlying bedrock is coarse textured Paskapoo sandstone which is generally found within 15 feet of the surface. The till generally has many characteristics similar to those of the underlying bedrock. The color is a light olive brown to a dark yellowish brown, being friable to firm in consistency. Olive colored shale chips, yellow sandstone fragments and coal flakes are common. The texture of the Breton till is a loam, with 75 per cent of the sand separates being in the fine and very fine size ranges. The material is characterized by an average bulk density of 1.54 g./c.c., a relatively deep overlying soil profile, 98 per cent of its pebbles smaller than 8 m.m. in size, a calcium carbonate content of less than 5 per cent, a relatively high cation exchange capacity and a low electrical conductivity indicating nonsalinity.

The till is generally stone poor to moderately stony, the pebbles mainly being a mixture of quartzites, limestones, soft sandstones, granites and iron concretions. The till was deposited by the Continental ice sheet as is indicated by a crystalline igneous and metamorphic pebble content of 14 per cent. There is generally a large variability in pebble composition between the sampling sites. The limestone content ranged from 0 to 20 per cent. The large variability likely reflects the distant source area from which these pebbles were derived and the

quantity of rock material incorporated into the body of the ice and subsequently transported to the point of deposition.

The majority of the total clay fraction in the Breton till is montmorillonite, illite and interlayered montmorillonite-illite. The average per cent montmorillonite in the Breton till comprises from 54 to 62 per cent of the clay minerals in the till. The high percentage of montmorillonite accounts for the high cation exchange capacity of the Breton till.

Quartz is the dominant mineral present in the fine sand fraction (S.G. < 2.96) of the Breton till. The main heavy minerals (S.G. > 2.96) identified are: opaques, amphiboles, garnets, epidotes, and pyroxenes constituting 52.2, 10.8, 8.2, 7.0, and 1.3 per cent of the heavy minerals, respectively. The opaques are mainly the iron oxides, limonite, hematite and magnetite.

The Hubalta till is found on undulating to hilly topography at an elevation generally between 2700 and 3500 feet above sea level. The land form is generally ground moraine with the underlying bedrock being the Paskapoo Formation. The till is generally underlain by the coarse textured Paskapoo sandstone, however olive green shales have also been observed in the region. The till is olive brown in color, friable to firm in consistency, generally stone poor and contains olive colored chips and coal fragments. The Hubalta till was deposited by the Continental ice sheet. Little variability in particle size distribution was noted in the material, the texture being a clay loam.

The Hubalta till is finer textured than the Breton till, however the montmorillonite content in the clay fraction is lower. Other than clay mineralogy and texture, the Hubalta and Breton tills have similar characteristics.

The similarity of the Hubalta and Breton tills reflects the fact that they are deposited by the Continental ice sheet and that they are underlain by the same bedrock formation. The Paskapoo Formation is comprised of sandy, silty and shaley members. The preglacial landscape in west-central Alberta has been dissected by drainage as is indicated by long broad valleys in the region. The dissection of the landscape could concievably expose different members within a formation and thus give rise to different properties for tills underlain by the same formation. This is thought to have occurred with the Hubalta till which is underlain in the majority of cases by the coarse textured soft sandstone beds of the Paskapoo Formation.

The Hubalta and Hubalta-Breton intergrade till groups, from the Chip Lake map area were found to be reasonably similar to the Hubalta till. Generally a greater variability was found in the 2 groups of till from the Chip Lake map area than in the representative Hubalta till group, but this is to be expected since the samples were selected at random. Although the Hubalta-Breton intergrade till group was found to be more similar to the representative Hubalta till group the montmorillonite content was found to be similar to the Breton till.

In conclusion the analytical results substantiate the initial field classification of the tills in the Chip Lake map area.

The Lobley, Hubalta, Cooking Lake and Breton tills were found to have characteristic differentiating properties and thus justifies the separation of the soils developed from the glacial till parent materials into different soil Series. The differentiating properties, of the tills studied, may be of beneficial use to the engineer, forester, glacial geologist and agrologist in future applied research.

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APPENDIX A

TABLE Ic - Mechanical Analysis of the Reference Till Samples

Sample Number		Sand* (%)	Silt* (%)	Clay* (%)	Fine* Clay (%)	Sand Fractions** V.C.S. (%)	C.S. (%)	M.S. (%)	F.S. (%)	V.F.S. (%)
1	Cooking Lake Till	45	34	21	10	7.4	17.3	14.8	33.9	26.6
2		43	36	21	10	2.3	19.8	15.3	36.3	26.3
3		39	35	26	13	4.3	10.6	15.5	38.6	31.0
4		44	32	24	12	6.9	15.4	17.0	37.9	22.8
5		40	35	25	14	3.9	13.0	16.9	42.0	24.2
6	Breton Till	40	38	22	9	1.3	7.7	15.5	46.3	29.2
7		39	37	24	10	1.6	8.4	15.7	44.4	29.9
8		34	39	27	12	1.4	7.2	13.5	38.8	39.1
9		38	40	22	8	2.9	10.1	16.6	35.0	35.4
10		37	41	22	11	2.1	7.7	15.8	47.1	27.3
11	Lobley Till	30	50	20	7	2.0	5.2	14.1	39.0	39.8
12		31	40	29	11	5.8	7.9	10.8	38.6	36.9
13		29	45	26	8	4.3	6.5	12.3	38.1	38.8
14		21	43	36	12	4.3	7.1	12.9	38.5	37.2
15		26	40	34	12	5.1	9.0	15.9	37.6	32.5
16	Hubalta Till	32	35	33	14	1.9	8.6	16.5	42.6	30.4
17		29	35	36	16	2.9	10.8	15.2	41.9	29.2
18		33	33	34	13	1.1	11.8	15.8	41.5	29.8
19		27	44	29	14	0.6	4.6	11.6	44.3	38.9
20		30	37	33	18	2.4	9.5	16.5	42.9	28.8
21		30	37	33	19	2.1	8.7	16.4	45.6	26.2
22		30	36	34	20	1.0	7.1	12.0	43.0	36.9

* - Average from duplicate samples

** - Based on summation of sand fraction

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C **ANALYSIS OF VARIANCE FOR THE COMPLETELY RANDOM DESIGN WITH ANY NUMBER OF
C   GROUPS WITH EQUAL OR UNEQUAL REPLICATION. PROGRAM ALSO CARRIES OUT A
C   DUNCAN'S MULTIPLE RANGE TEST.**
      REAL SSR(100),NAME(17),V(100),X(100),C(100),D(100),P(100)
    1 FORMAT(I4,F8.3,17A4)
    2 FORMAT(20F4.2/(20F4.2))
    3 FORMAT(2(I2,2X),8F8.3/(10F8.3))
    4 FORMAT('1',//,20X,'ANALYSIS OF VARIANCE AND DUNCAN,'' ,'S NEW MULT
     1IPLE RANGE TEST',//,20X,17A4//,'  MEANS---------------',10F11.4/(2
     32X,10F11.4))
    5 FORMAT(/,'  STANDARD DEVIATIONS-',10F11.4/(22X,10F11.4))
    7 FORMAT(////,30X,'ANOVA TABLE' //,'          SOURCE           DEGREES
     1OF FREEDOM     SUMS OF SQUARES        MEAN SQUARE            F-VA
     2LUE' //,' AMONG TREATMENTS   4F21.4/,' WITHIN TREATMENTS' 3F21.4/,
     3' TOTAL',12X      ,2F21.4///,'     **** THE F-VALUE FROM THE TABL
     4E IS' F8.3   ****' ////,25X,'TABLE OF RANKED MEAN DIFFERENCES WITH
     5 CORRESPONDING',/,25X,'LEAST SIGNIFICANT RANGES PUT DIRECTLY BELOW
     5 EACH DIFFERENCE  '//)
    8 FORMAT(15X,'  MEANS',10F11.4/(22X,10F11.4))
    9 FORMAT(11X,11F11.4/(22X,10F11.4))
   10 FORMAT(22X,10F11.4/(22X,10F11.4))
   11 SS=0.0
      TT=0.0
      TN=0.0
      TR=0.0
      READ(5,1,END=21) NT,TF,NAME
      M=NT-1
      READ(5,2)  (SSR(I),I=1,M)
      DO 16 L=1,NT
      S=0.0
      T=0.0
      READ(5,3)  J,N, (V(I),I=1,N)
      DO 12 I=1,N
      S=S+V(I)**2
      T=T+V(I)
   12 CONTINUE
      X(J)=T/N
      C(J)=N
      IF (S-T**2/N) 13,14,15
   13 D(J)=SQRT((S-T**2/N)/(N-1))
      GOTO15
   14 D(J)=0.0
   15 SS=SS+S
      TT=TT+T
      TN=TN+N
      TR=TR+T**2/N
   16 CONTINUE
      SS=SS-TT**2/TN
      TR=TR-TT**2/TN
      ES=SS-TR
      SF=TN-1.
      EF=TN-NT
      FF=SF-EF
      TM=TR/FF
      EM=ES/EF
      F=TM/EM
      WRITE(6,4)  (NAME(I),I=1,17), (X(I),I=1,NT)
      WRITE(6,05)  (D(I),I=1,NT)
      WRITE(6,07)  FF,TR,TM,F,EF,ES,EM,SF,SS,TF
      DO 18 I=1,M
      DO 17 J=2,NT
      IF(X(J-1).LE.X(J)) GOTO17
      TEMP=X(J-1)
      X(J-1)=X(J)
      X(J)=TEMP
      TEMP=C(J-1)
      C(J-1)=C(J)
      C(J)=TEMP
   17 CONTINUE
   18 CONTINUE
      WRITE(6,08)  (X(I),I=1,M)
      DO 20 I=1,M
      K=NT-I
      DO 19 J=1,K
      B=X(K+1)
      P(J)=B-X(J)
      N=K-J+1
      D(J)=SSR(N)*SQRT(EM/2.*(1./C(K+1)+1./C(J)))
   19 CONTINUE
      WRITE(6,09)  B, (P(J),J=1,K)
      WRITE(6,10)  (D(J),J=1,K)
   20 CONTINUE
      GOTO11
   21 STOP
      END
```

Figure Ic - Computer Program

TABLE IIc - Some Physical Characteristics of the Reference Till Samples

Sample Number		Bulk Density (g./cc.)*	Penetrometer values (tons/ft.^{2})**	Depth of profile (inches)	R.S.G.
1	Cooking Lake Till	1.46	3.7	35	2.59
2	Cooking Lake Till	1.64	3.1	36	2.62
3	Cooking Lake Till	1.57	4.5	37	2.61
4	Cooking Lake Till	1.68	2.8	36	2.63
5	Cooking Lake Till	1.72	4.5	35	2.58
6	Breton Till	1.48	4.1	60	2.59
7	Breton Till	1.47	1.4	60	2.59
8	Breton Till	1.59	3.5	61	2.65
9	Breton Till	1.53	1.4	60	2.61
10	Breton Till	1.65	2.7	56	2.60
11	Lobley Till	1.66	2.1	44	2.63
12	Lobley Till	1.55	2.7	30	2.66
13	Lobley Till	1.57	2.5	30	2.60
14	Lobley Till	1.55	2.9	32	2.59
15	Lobley Till	1.56	1.4	24	2.60
16	Hubalta Till	1.37	1.75	48	2.59
17	Hubalta Till	1.48	1.4	38	2.57
18	Hubalta Till	1.53	2.3	38	2.60
19	Hubalta Till	1.44	1.65	66	2.61
20	Hubalta Till	1.46	1.4	45	2.59
21	Hubalta Till	1.44	2.3	72	2.57
22	Hubalta Till	1.56	2.3	52	2.57

* - Average from a minimum of 2 cores
** - Average from 25 readings

TABLE IIIc - Unconfined Compression Data for some of the Reference Till Samples

Site #8 SE 30-50-7-W5 % Moisture=15.7 Breton Till		Site #8 SE 30-50-7-W5 % Moisture=15.2 Breton Till		Site #17 NE 32-52-13-W5 % Moisture=21.0 Hubalta Till		Site #17 NE 32-52-13-W5 % Moisture=19.8 Hubalta Till		Site #4 SE 36-51-20-W4 % Moisture=19.5 Cooking Lake Till		Site #2 SW 6-55-19-W4 % Moisture=19.6 Cooking Lake Till	
Stress*	Strain**	Stress*	Strain**	Stress*	Strain**	Stress*	Strain**	Stress*	Strain**	Stress*	Strain**
24.17	.0056	3.06	.0044	8.20	.0041	12.36	.0064	10.4	.0045	16.1	.0088
35.00	.0130	10.14	.0084	13.75	.0139	21.67	.0139	13.7	.0089	19.9	.0180
43.62	.0196	17.08	.0090	18.75	.0223	29.03	.0222	20.8	.0130	23.7	.0260
48.06	.0262	21.81	.0136	22.92	.0290	33.33	.0306	24.7	.0180	26.1	.0310
34.17	.0347	29.45	.0173	25.97	.0363	36.11	.0388	28.2	.0220	28.6	.0400
27.09	.0423	35.28	.0244	28.89	.0430	38.75	.0483	30.4	.0270	29.7	.0440
25.28	.0502	42.09	.0277	32.64	.0499	39.86	.0563	32.4	.0310	31.6	.0540
25.00	.0598	46.39	.0342	35.42	.0562	40.28	.0632	33.4	.0360	32.7	.0620
22.50	.0707	49.17	.0374	37.50	.0628	40.98	.0689	34.7	.0400	33.9	.0710
16.25	.0870	48.89	.0452	39.45	.0700	41.11	.0755	35.7	.0450	33.7	.0800
10.83	.1130	35.84	.0511	41.25	.0821	40.00	.0860	36.2	.0490	34.5	.0930
6.95	.1404	29.59	.0615	43.06	.0941	37.36	.0988	36.7	.0540	34.0	.1250
3.33	.1620	18.20	.0760	44.03	.1050	32.64	.1130	37.1	.0610		
				44.03	.1183	25.83	.1290	37.8	.0670		
				44.17	.1292	21.39	.1453	38.2	.0710		
				44.31	.1340	11.81	.1608	38.6	.0760		
				42.78	.1680			38.8	.0800		
				42.09	.1840			38.9	.0890		
								39.2	.0940		
								39.2	.1030		
								39.2	.1070		
								38.9	.1120		
								38.4	.1160		
								38.0	.1210		
								37.6	.1250		
								36.9	.1300		

* Pounds per square inch (p.s.i.)

** inch per inch of sample length (in./in.)

TABLE IVc - Unconfined Compression Data for some of the Lobley Reference Till Samples

Site #13 NE 34-37-8-W5 % Moisture=14.0		Site #13 NE 34-37-8-W5 % Moisture=13.6		Site #14 NW 30-33-5-W5 % Moisture=17.2		Site #12 SW 27-40-10-W5 % Moisture=16.7		Site #12 SW 27-40-10-W5 % Moisture=16.3		Site #12 SW 27-40-10-W5 % Moisture=14.9	
Stress*	Strain**	Stress*	Strain**	Stress*	Strain**	Stress*	Strain**	Stress*	Strain**	Stress*	Strain**
4.20	.0049	15.2	.0046	6.9	.0077	2.4	.0047	7.5	.0060	10.9	.0090
				9.1	.0116	3.7	.0090	11.2	.0110	14.5	.0139
12.9	.0098	26.5	.0093	12.0	.0170	4.8	.0135	14.8	.0170	17.1	.0180
				13.8	.0232	5.7	.0182	17.1	.0220	20.0	.0225
21.3	.0147	27.7	.0115	15.6	.0291	6.3	.0234	19.5	.0340	21.8	.0268
				16.4	.0352	7.5	.0268	21.0	.0380	23.3	.0315
26.3	.0196	25.1	.0139	17.1	.0407	8.4	.0314	22.2	.0440	24.7	.0362
				17.9	.0457	9.0	.0363	24.0	.0490	26.0	.0408
41.8	.0245	11.6	.0185	18.9	.0511	9.3	.0406	24.6	.0550	27.0	.0450
				18.8	.0572	9.6	.0450	25.2	.0610	27.7	.0504
39.1	.0294			18.7	.0635	9.8	.0494	25.9	.0660	28.6	.0540
				19.6	.0678	9.9	.0541	26.2	.0710	29.0	.0585
				19.5	.0739	10.5	.0584	27.2	.0770	29.5	.0638
				19.4	.0799	10.4	.0628	27.1	.0830	30.6	.0675
				19.3	.0853	10.4	.0685	27.5	.0880	31.0	.0718
				19.5	.0910	10.8	.0720	28.2	.0940	31.7	.0760
				18.3	.0979	10.7	.0764	27.9	.0990	31.5	.0827
						10.8	.0809	28.0	.1040	31.3	.0883
						10.2	.0851				
						10.0	.0911				

* Pounds per square inch (p.s.i.)
** inch per inch of sample length (in./in.)

TABLE Vc - Coarse Fragment Distribution of the Reference Till Samples

Sample Number		<128mm.* >64mm.(%)	<64mm.* >32mm.(%)	<32mm.* >16mm.(%)	<16mm.* > 8mm.(%)	< 8mm.* >4mm.(%)	<4mm.* >2mm.(%)
1	Cooking Lake Till	0.01	0.03	0.2	1.6	7.3	90.8
2		0.02	0.04	0.2	1.9	7.9	89.9
3		0.00	0.03	0.1	1.4	6.8	91.6
4		0.01	0.01	0.2	0.8	3.8	95.2
5		0.00	0.02	0.1	1.9	6.2	91.7
6	Breton Till	0.06	0.00	0.1	2.3	18.4	79.1
7		0.01	0.00	0.1	1.0	8.5	90.4
8		0.00	0.00	0.4	1.6	12.2	85.8
9		0.00	0.10	0.5	2.5	10.4	86.6
10		0.04	0.04	0.3	1.7	15.5	82.4
11	Lobley Till	0.02	0.11	0.7	5.1	19.3	74.8
12		0.01	0.10	0.5	4.2	20.1	75.1
13		0.02	0.14	0.9	4.5	22.0	72.5
14		0.04	0.10	0.6	3.8	16.0	79.5
15		0.01	0.07	0.8	4.7	18.4	76.0
16	Hubalta Till	0.00	0.10	0.4	5.3	24.2	70.0
17		0.00	0.00	0.2	4.1	18.7	77.0
18		0.10	0.40	0.5	3.6	17.4	78.0
19		0.00	0.40	0.7	1.7	13.3	83.9
20		0.00	0.00	0.1	1.3	3.4	95.2
21		0.08	0.00	0.4	1.1	10.0	88.4
22		0.00	0.10	0.7	2.1	12.5	84.6

* - Per cent (%) by number

TABLE VIc - Pebble Count Distribution of the Reference Till Samples

Sample Number		Limestones* (%)	Sandstones* (%)	Dolomites* (%)	Quartzites* (%)	Granites* (%)	Others* (%)●	Sandstones* + Quartzites (%)
1	Cooking Lake Till	13.8	22.1	6.4	28.1	11.2	18.4	50.2
2		7.9	24.6	1.3	33.8	10.5	21.9	58.4
3		10.2	22.0	0.8	32.2	14.3	20.5	54.4
4		10.0	18.0	1.8	29.5	25.0	15.7	47.5
5		24.1	23.2	0.0	20.1	7.6	25.0	43.3
6	Breton Till	1.6	25.3	0.3	41.5	10.4	20.9	66.8
7		0.2	29.5	0.0	47.0	6.3	17.0	76.5
8		0.0	23.5	0.0	48.4	6.5	21.7	71.9
9		0.0	15.7	0.0	47.9	17.4	19.0	63.6
10		19.7	23.1	0.0	20.0	5.2	32.0	43.1
11	Lobley Till	30.2	9.2	0.0	56.8	0.3	3.5	66.0
12		35.5	28.6	1.2	23.6	0.3	10.8	52.2
13		30.4	23.0	0.0	30.6	0.0	16.0	53.6
14		45.8	12.0	0.6	37.8	0.3	3.5	49.8
15		41.4	16.4	2.0	34.3	0.2	5.7	50.7
16	Hubalta Till	20.8	7.4	3.7	31.4	13.9	22.8	38.8
17		27.2	6.6	2.1	29.1	18.8	16.2	35.7
18		4.8	10.4	0.8	47.6	13.7	22.7	58.0
19		19.9	34.3	1.4	14.0	11.5	18.9	48.3
20		0.6	40.5	0.0	31.4	11.1	16.4	71.9
21		0.0	37.3	0.0	42.3	9.7	10.7	79.6
22		0.0	37.1	0.0	19.3	20.5	23.1	56.4

* - Per cent (%) by number

● - For pebble composition see Table 14A

TABLE VIIc - Some Chemical Characteristics of the Reference Till Samples

Sample Number		$CaCO_3$ (%)	C.E.C.* me./100g.	Fe (%)	Al (%)	Fe + Al (%)	pH
1	Cooking Lake Till	3.64	13.4	0.64	0.28	0.92	7.6
2		1.89	14.8	0.74	0.09	0.83	7.2
3		3.63	16.6	0.83	0.08	0.91	7.3
4		6.23	12.0	0.66	0.09	0.75	7.6
5		5.32	13.7	0.77	0.10	0.87	7.6
6	Breton Till	4.14	18.6	0.66	0.07	0.73	7.6
7		4.87	19.6	0.66	0.07	0.73	7.7
8		3.06	18.3	0.74	0.10	0.84	7.2
9		1.36	20.4	0.78	0.09	0.87	7.5
10		5.37	19.9	0.70	0.09	0.79	7.4
11	Lobley Till	10.63	13.4	0.63	0.09	0.72	7.7
12		14.68	14.6	0.77	0.09	0.86	7.8
13		7.13	16.3	0.68	0.09	0.77	7.9
14		9.22	19.4	0.78	0.08	0.86	7.6
15		10.34	19.4	0.74	0.09	0.83	7.7
16	Hubalta Till	1.63	21.2	0.96	0.10	1.06	7.2
17		3.46	20.4	0.79	0.30	1.09	7.2
18		3.60	21.1	0.77	0.07	0.84	7.2
19		3.12	21.8	0.66	0.08	0.74	7.5
20		3.42	20.6	0.90	0.08	0.98	7.4
21		4.50	19.9	0.78	0.09	0.87	7.3
22		2.60	21.6	0.94	0.09	1.03	7.3

* Average values of duplicate determinations

TABLE VIIIc - Electrical Conductivity and Soluble Salts of the Reference Till Samples

Sample Number		Electrical Cond. (mmhos/cm.²)	Soluble Salts (me./litre)			
			Na^+	K^+	Mg^{++}	Ca^{++}
1	Cooking Lake Till	0.50	1.04	0.24	1.48	7.00
2	Cooking Lake Till	0.35	1.26	0.09	1.19	6.38
3	Cooking Lake Till	0.42	1.87	0.12	1.60	8.88
4	Cooking Lake Till	0.51	1.04	0.17	1.70	10.13
5	Cooking Lake Till	0.40	1.22	0.09	0.94	5.75
6	Breton Till	0.28	1.44	0.05	1.11	9.25
7	Breton Till	0.21	0.78	0.05	0.88	8.88
8	Breton Till	0.25	0.87	0.13	1.05	9.50
9	Breton Till	0.36	0.65	0.17	1.09	10.13
10	Breton Till	0.30	1.00	0.08	0.62	5.50
11	Lobley Till	0.38	0.74	0.08	1.21	9.75
12	Lobley Till	0.31	0.83	0.09	1.15	9.50
13	Lobley Till	0.24	0.87	0.04	0.98	9.25
14	Lobley Till	0.21	0.74	0.05	0.90	8.38
15	Lobley Till	0.20	1.48	0.07	1.03	8.63
16	Hubalta Till	0.25	1.13	0.06	0.78	5.75
17	Hubalta Till	0.60	0.61	0.07	0.74	6.00
18	Hubalta Till	0.23	0.87	0.08	0.74	5.75
19	Hubalta Till	0.24	0.91	0.14	1.17	9.25
20	Hubalta Till	0.26	0.96	0.06	1.00	8.88
21	Hubalta Till	0.33	2.52	0.11	1.80	11.13
22	Hubalta Till	0.25	1.22	0.07	1.09	8.88

TABLE IXc - Light and Heavy Mineral Distribution of the Reference Till Samples

Sample Number		Light Minerals (S.G.< 2.96) (%)	Heavy Minerals (S.G.>2.96) (%)
1	Cooking Lake Till	99.27	0.73
2		99.04	0.96
3		99.11	0.89
4		98.55	1.45
5		98.88	1.12
6	Breton Till	99.13	0.87
7		99.09	0.91
8		99.10	0.90
9		99.18	0.82
10		99.12	0.88
11	Lobley Till	99.26	0.74
12		99.35	0.65
13		99.14	0.86
14		98.96	1.04
15		99.30	0.70
16	Hubalta Till	99.02	0.98
17		99.05	0.95
18		99.17	0.83
19		99.22	0.78
20		99.04	0.96
21		99.30	0.70
22		99.20	0.80

Table Xc - Quantitative Estimates for the Light Mineral Distribution of the Reference Till Samples (S.G.<2.96)

Sample Number		K_2O (%)	Na_2O (%)	CaO (%)	K Feldspar (%)	Soda-Calcic Feldspar (%)	Total Feldspar (%)	Quartz* (%)	Feldspar/Quartz Ratio
1	Cooking Lake Till	1.10	1.26	0.35	6	13	19	81	0.234
2		1.51	1.75	0.45	9	17	26	74	0.351
3		1.13	1.21	0.43	7	12	19	81	0.234
4		1.07	1.26	0.52	6	14	20	80	0.250
5		0.93	0.96	0.77	5	12	17	83	0.205
6	Breton Till	1.78	2.09	0.62	10	21	31	69	0.449
7		1.88	2.22	0.74	11	23	34	66	0.515
8		1.51	1.75	0.67	9	18	27	73	0.370
9		1.58	1.68	0.61	9	17	26	74	0.351
10		1.58	2.00	0.74	9	21	30	70	0.428
11	Lobley Till	1.43	1.82	0.47	8	17	25	75	0.333
12		1.54	2.07	0.75	9	22	31	69	0.449
13		1.63	2.09	0.47	10	20	30	70	0.428
14		1.20	1.55	0.37	7	15	22	78	0.282
15		1.33	1.33	0.39	8	13	21	79	0.266
16	Hubalta Till	1.51	1.33	0.75	9	15	24	76	0.316
17		1.43	1.87	0.75	8	20	28	72	0.389
18		1.73	2.07	0.79	10	22	32	68	0.470
19		1.63	1.94	1.08	10	21	31	69	0.449
20		1.36	1.58	0.62	8	16	24	76	0.316
21		1.13	1.33	0.41	7	13	20	80	0.250
22		1.73	2.32	0.79	10	24	34	66	0.515

* Determined by difference

TABLE XIc

TABLE XIc - Heavy Mineral Distribution of the Reference Till Samples ($S.G. > 2.96$)

Mineral	Cooking Lake Till* 1	2	3	4	5	Breton Till* 6	7	8	9	10
Magnetite	5	11	7	8	4	11	10	12	5	3
Hematite	23	15	23	10	21	21	10	15	31	22
Limonite	19	12	14	4	10	14	16	12	24	20
Total Fe Oxides	47	38	44	22	35	46	36	39	60	45
Leucoxene	1	2	3	1	3	2	4	3	3	2
Other Opaques	3	3	3	1	1	4	3	6	3	5
Total Opaques	51	43	50	24	39	52	43	48	66	52
Topaz	-	-	-	-	T	-	-	-	-	T
Amphiboles	23	24	21	41	29	10	11	16	10	7
Garnets	9	14	10	12	9	9	13	6	9	4
Epidote	3	3	4	4	3	8	10	5	3	9
Pyroxene	3	3	2	2	3	T	2	2	1	1
Staurolite	T	1	1	2	1	2	2	T	1	2
Zoisite**	T	1	T	T	-	2	-	3	1	3
Biotite	2	-	-	2	1	2	T	2	1	2
Chlorite	T	T	T	1	1	1	2	1	T	2
Andalusite	-	T	T	1	1	T	T	-	T	T
Rutile	-	-	T	T	-	T	T	T	T	1
Zircon	T	T	T	1	1	1	1	1	T	1
Monazite	T	T	1	T	1	T	1	-	1	-
Apatite	T	T	T	1	T	T	-	-	T	T
Tourmaline	T	1	1	T	T	1	T	-	T	-
Kyanite	-	-	-	T	T	T	-	T	T	T
Sillimanite	-	1	1	1	T	-	-	-	-	-
Volcanic	-	-	-	-	-	-	-	-	-	-
Unidentified	5	5	5	5	7	10	13	13	3	12

T Trace (less than 1%)
* All values expressed as per cent of total mineral grains counted (minimum of 300 grains)
** Also includes clinozoisite

TABLE XIc - Continued

Mineral	Lobley Till*						Hubalta Till*						
	11	12	13	14	15	15A***	16	17	18	19	20	21	22
Magnetite	13	7	4	4	14	2	3	8	9	10	6	9	10
Hematite	22	27	33	32	25	43	30	21	20	19	23	14	15
Limonite	11	19	32	37	21	5	22	13	5	6	15	9	12
Total Fe Oxides	46	53	69	73	60	50	55	42	34	35	43	32	37
Leucoxene	5	3	2	3	7	3	2	1	2	2	1	2	3
Other Opaques	2	13	5	8	4	34	2	3	2	5	3	3	2
Total Opaques	53	69	76	84	71	87	59	46	38	42	47	37	42
Topaz	-	-	-	-	-	-	T	-	-	-	-	-	T
Amphiboles	1	-	T	1	2	-	7	13	10	11	16	18	16
Garnets	10	4	2	2	3	2	6	9	11	9	12	15	15
Epidote	9	5	4	4	5	3	7	7	7	8	5	6	5
Pyroxene	2	T	T	-	-	-	1	2	2	2	3	2	2
Staurolite	2	-	T	-	2	-	2	1	1	2	T	2	2
Zoisite**	1	T	-	-	-	-	-	1	1	1	-	-	1
Biotite	1	4	T	T	T	T	T	-	3	3	T	T	2
Chlorite	2	2	4	T	1	2	1	2	3	3	2	1	1
Andalusite	1	T	T	T	1	-	T	1	T	T	1	-	T
Rutile	1	T	T	1	T	-	-	T	T	1	-	-	-
Zircon	3	3	2	1	4	1	1	2	T	1	T	2	T
Monazite	T	-	-	-	-	-	1	1	1	1	T	1	1
Apatite	T	-	-	T	T	-	2	2	2	2	T	1	1
Tourmaline	1	1	T	-	1	-	T	T	-	1	T	1	1
Kyanite	T	T	-	-	-	-	T	-	-	T	1	1	-
Sillimanite	-	-	-	-	-	-	-	-	-	-	T	1	T
Volcanic	T	3	2	T	3	3	-	-	-	-	-	-	-
Unidentified	11	6	7	5	5	2	10	12	20	12	10	12	8

T Trace (less than 1%)

* All values expressed as per cent of total mineral grains counted (minimum of 300 grains)

** Also includes clinozoisite

*** An extra till sample for heavy mineral identification only

APPENDIX B TABLE XIIc

Mechanical Analysis of the Till Samples from the Chip Lake and Adjacent areas

Sample Number		Sand* (%)	Silt* (%)	Clay* (%)	Fine* Clay (%)	Sand Fractions** V.C.S. (%)	C.S. (%)	M.S. (%)	F.S. (%)	V.F.S. (%)
24		36	38	26	13	1.7	8.3	16.0	40.7	33.1
25	Hubalta Till from the Chip Lake map area	27	36	37	16	1.5	11.4	17.3	39.4	29.9
26		32	35	33	18	2.0	9.8	12.8	43.4	31.9
27		33	36	31	17	1.8	10.0	15.9	41.9	30.2
31		31	34	35	15	3.0	13.3	15.9	39.1	28.5
34		24	40	35	18	3.4	16.1	14.5	36.8	29.0
36		33	34	33	15	4.2	10.7	16.5	41.3	27.2
38		33	34	33	18	2.2	9.0	17.2	44.8	26.8
41		38	30	32	18	2.9	11.8	17.8	42.0	25.5
42		31	33	36	20	1.4	7.3	14.2	42.2	34.8
43		31	33	36	19	4.2	12.6	17.2	36.0	30.0
28	Hubalta-Breton Till inter-grade from the Chip Lake map area	30	34	36	17	2.0	6.3	10.8	42.3	38.2
29		31	37	32	15	1.6	11.1	14.5	42.1	30.4
32		30	37	33	14	1.0	7.4	13.6	45.2	32.5
35		34	39	27	12	1.2	6.3	14.3	45.8	32.1
37		37	32	31	18	3.0	12.6	17.2	42.4	24.6
39		13	48	39	18	1.1	7.5	15.1	42.6	33.6
40		33	36	31	17	2.0	8.0	14.7	43.7	31.6
23	Till from the Chip Lake and adjacent areas	37	32	31	15	3.3	14.9	19.0	37.4	25.2
30		33	39	28	15	4.8	14.9	16.1	37.0	27.0
33		46	29	22	11	1.7	16.1	18.0	41.3	22.6
44		38	33	29	14	0.7	7.2	14.9	48.4	28.8
45		54	29	17	11	4.3	14.0	21.7	43.3	16.7
46		22	51	27	6	1.8	6.7	14.8	34.6	42.1

* - Average from duplicate samples

** - Based on summation of sand fraction

TABLE XIIIc

Some Physical Characteristics of the Till Samples from the Chip Lake and Adjacent areas

Sample Number		Bulk Density (g./cc.)*	Penetrometer values (tons/ft.^{2})**	Depth of profile (inches)	R.S.G.
24	Hubalta Till from the Chip Lake map area	1.48	2.8	59	2.58
25		1.53	1.6	48	2.58
26		1.45	1.6	45	2.58
27		1.50	1.4	48	2.57
31		1.45	1.3	40	2.58
34		1.46	1.6	48	2.61
36		1.41	1.2	53	2.61
38		1.44	1.4	48	2.57
41		1.47	1.7	>84	2.59
42		1.59	1.6	>72	2.60
43		1.59	4.5	63	2.61
28	Hubalta-Breton Till intergrade from the Chip Lake map area	1.46	1.5	48	2.58
29		1.46	2.0	42	2.59
32		1.23	0.9	45	2.57
35		1.48	1.5	60	2.58
37		1.60	3.1	40	2.60
39		1.49	2.2	58	2.56
40		1.60	1.8	44	2.62
23	Till from the Chip Lake and adjacent areas	1.61	1.2	52	2.64
30		1.47	1.5	55	2.60
33		1.53	1.7	40	2.63
44		1.61	1.4	63	2.62
45		1.55	2.7	25	2.66
46		-	2.0	-	2.62

* - Average from a minimum of 2 cores

** - Average from 25 readings

TABLE XIVc

Coarse Fragment Distribution of the Till Samples from the Chip Lake and Adjacent areas

Sample Number		<128mm.* >64mm.(%)	<64mm.* >32mm.(%)	<32mm.* >16mm.(%)	<16mm.* >8mm.(%)	<8mm.* >4mm.(%)	<4mm.* >2mm.(%)
24		0.10	0.30	0.4	2.2	15.0	82.0
25	Hubalta Till from the Chip Lake map area	0.00	0.20	0.3	2.7	21.6	75.3
26		0.20	0.20	2.1	6.1	26.1	65.2
27		0.04	0.16	0.2	3.5	16.9	79.2
31		0.03	0.00	0.2	1.4	6.7	91.7
34		0.00	0.02	0.2	3.6	13.9	82.3
36		0.10	0.40	0.6	3.8	21.3	73.7
38		0.00	0.04	0.2	0.7	6.7	92.3
41		0.00	0.00	0.2	3.1	16.0	80.7
42		0.00	0.08	0.1	1.5	8.7	89.6
43		0.04	0.02	0.2	1.2	8.3	90.4
28	Hubalta-Breton Till intergrade from the Chip Lake map area	0.00	0.40	0.6	3.8	34.0	61.2
29		0.00	0.20	0.3	2.2	15.5	81.8
32		0.30	0.80	3.0	6.0	20.8	69.1
35		0.00	0.16	0.6	5.2	17.9	76.1
37		0.10	0.10	0.5	3.9	14.3	81.1
39		0.05	0.05	0.4	2.1	14.2	83.2
40		0.03	0.17	0.2	1.4	9.7	88.5
23	Till from the Chip Lake and adjacent areas	0.02	0.02	0.1	1.7	6.1	92.1
30		0.03	0.07	0.5	3.2	10.8	85.4
33		0.04	0.12	0.3	2.4	10.4	86.7
44		0.02	0.02	0.1	0.9	7.2	91.8
45		0.01	0.11	0.4	2.7	17.8	79.0
46		0.01	0.02	0.2	1.8	13.7	84.3

* - Per cent (%) by number

TABLE XVc - Pebble Count Distribution of the Till Samples from the Chip Lake and Adjacent areas

Sample Number		Limestones* (%)	Sandstones* (%)	Dolomites* (%)	Quartzites* (%)	Granites* (%)	Others* (%) ○	Sandstones* + Quartzites (%)
24	Hubalta Till from the Chip Lake map area	0.9	20.1	0.0	56.3	10.6	12.1	76.4
25		9.4	8.9	0.8	44.2	19.7	17.0	53.1
26		0.3	9.7	0.0	67.8	8.8	13.4	77.5
27		2.0	11.2	0.0	54.8	12.2	19.8	66.0
31		0.6	11.7	0.0	52.0	14.6	21.1	63.7
34		10.2	9.2	1.3	34.0	23.4	21.9	43.2
36		3.1	35.1	1.4	24.9	19.8	15.7	60.0
38		8.9	20.1	0.4	38.3	17.2	15.1	58.4
41		0.7	34.5	0.2	33.3	16.1	15.2	67.8
42		2.8	17.0	0.0	49.4	16.4	14.4	66.4
43		0.0	16.8	0.0	34.1	28.9	20.2	50.9
28	Hubalta-Breton intergrade from C.L. map	0.0	5.6	0.3	66.2	8.7	19.2	71.8
29		0.3	11.8	0.0	56.0	11.5	20.4	67.8
32		0.6	11.8	0.0	64.6	12.1	10.9	76.4
35		0.0	46.7	0.0	25.0	11.2	17.1	71.7
37		16.3	48.1	0.9	12.5	11.9	10.4	60.0
39		13.5	33.7	4.0	32.4	9.8	6.6	66.1
40		14.0	30.7	1.1	37.6	4.4	12.2	68.3
23	Till from C.L. map and adjacent areas	4.9	5.8	2.7	46.1	19.2	21.3	51.9
30		3.0	10.4	0.5	50.5	13.5	22.1	60.9
33		4.3	1.9	2.7	64.7	15.8	10.6	66.6
44		2.5	38.1	0.0	22.1	2.5	34.8	60.2
45		22.1	30.8	4.6	38.4	0.0	4.1	69.2
46		0.0	33.9	0.0	17.9	0.0	48.2	51.8

* - Per cent (%) by number

○ For Composition see Table 21A

TABLE XVIc
Some Chemical Characteristics of the Till Samples from the Chip Lake and Adjacent areas

Sample Number		$CaCO_3$ (%)	C.E.C.* me./100g.	Fe (%)	Al (%)	Fe + Al (%)	pH
24	Hubalta Till from the Chip Lake map area	3.09	18.4	0.74	0.09	0.83	7.4
25		2.86	19.1	0.88	0.37	1.25	7.3
26		3.06	20.8	0.85	0.09	0.94	7.1
27		3.12	20.6	0.90	0.10	1.00	7.2
31		3.70	21.2	0.42	0.09	0.51	7.0
34		2.66	18.4	1.02	0.10	1.12	7.4
36		4.51	19.9	0.72	0.10	0.82	7.5
38		4.90	19.0	0.85	0.09	0.94	7.8
41		T**	18.2	0.90	0.14	1.04	6.2
42		T	21.7	0.96	0.09	1.05	6.1
43		T	18.1	1.14	0.10	1.24	6.3
28	Hubalta-Breton Till intergrade from the Chip Lake map area	6.81	20.4	0.72	0.08	0.80	7.2
29		3.99	19.6	0.75	0.34	1.09	7.3
32		2.24	22.3	0.77	0.09	0.86	7.3
35		4.55	20.7	0.70	0.08	0.78	7.8
37		3.84	17.1	0.78	0.08	0.86	7.7
39		5.60	24.0	0.83	0.10	0.93	7.8
40		7.33	17.0	0.78	0.09	0.87	7.9
23	Till from the Chip Lake and adjacent areas	3.61	14.0	0.94	0.12	1.06	7.3
30		4.20	17.0	0.88	0.08	0.96	7.4
33		6.71	10.5	0.53	0.08	0.61	7.5
44		2.10	19.4	0.77	0.08	0.85	7.2
45		8.78	14.0	0.48	0.07	0.55	7.3
46		T	18.1	0.63	0.08	0.71	5.7

** Trace
* Average values of duplicate determinations

TABLE XVIIc - Electrical Conductivity and Soluble Salts of the Till Samples from the Chip Lake and Adjacent areas

Sample Number		Electrical Cond. (mmhos/cm^2.)	Soluble Salts (me./litre)			
			Na^+	K^+	Mg^{++}	Ca^{++}
24	Hubalta Till from the Chip Lake map area	0.20	1.04	0.07	0.92	5.50
25		0.23	1.26	0.12	0.66	5.75
26		0.22	0.70	0.08	0.70	5.88
27		0.26	0.74	0.08	0.82	5.75
31		0.27	0.83	0.05	1.03	5.50
34		0.30	1.22	0.05	0.98	5.88
36		0.44	1.04	0.04	1.09	9.25
38		0.26	1.52	0.07	1.23	8.13
41		0.19	1.74	0.05	0.82	7.88
42		0.18	0.87	0.07	0.78	7.88
43		0.30	1.22	0.20	1.39	9.75
28	Hubalta-Breton Till intergrade from the Chip Lake map area	0.54	0.87	0.05	0.72	6.13
29		0.26	0.83	0.04	0.92	5.50
32		0.24	1.17	0.08	0.92	5.50
35		0.20	0.87	0.05	0.92	8.88
37		0.33	2.09	0.09	1.19	9.75
39		0.22	0.87	0.06	1.03	9.25
40		0.24	1.65	0.08	1.13	8.88
23	Till from the Chip Lake and adjacent areas	0.32	0.96	0.17	1.00	5.63
30		0.26	1.04	0.08	1.11	5.63
33		0.40	0.70	0.08	1.05	6.13
44		0.29	0.87	0.14	1.09	9.25
45		0.25	1.48	0.08	0.92	8.38
46		0.26	0.91	0.09	0.96	8.38

TABLE XVIIIc - Clay Mineral Determinations of the Till Samples from the Chip Lake and Adjacent areas

Group	Sample Number	C.E.C.** (me./100g.)	Surface*** Area ($m.^2/g.$)	K_2O (%)	Montmorillonite (%) (1)	Montmorillonite (%) (2)	% Mont. (mean)	Illite (%)	Chlorite* (%)	Kaolinite* (%)	Quartz* (%)
Hubalta Till from the Chip Lake map area	24	53.0	562	2.26	54	56	55	23	5-12	0-10	2-6
	25	42.0	477	2.32	42	47	45	23	5-12	10-20	2-6
	26	57.4	578	2.32	59	57	58	23	10-20	0-5	2-6
	27	54.3	575	2.05	56	57	56	21	0-5	3-8	2-6
	31	53.5	548	2.11	55	54	54	21	0-5	5-15	2-6
	34	42.2	426	2.50	42	42	42	25	0-5	10-20	2-6
	36	48.1	458	1.51	50	46	48	15	5-10	2-5	2-6
	38	50.1	535	1.85	52	53	53	18	2-5	5-10	2-6
	41	51.6	532	1.91	53	53	53	19	0-5	10-20	2-6
	42	47.1	540	2.38	47	54	51	24	0-5	5-15	2-6
	43	42.3	430	2.77	41	43	42	28	0-5	10-20	2-6
Hub.-Bn. Till intergrade from the C.L. map area	28	56.0	560	2.05	58	56	57	21	0-5	3-8	2-6
	29	50.5	538	2.32	51	54	52	23	0-5	3-8	2-6
	32	53.8	531	2.32	55	53	54	23	5-8	0-8	2-6
	35	53.7	560	2.11	55	56	56	21	5-12	2-5	2-6
	37	49.2	498	2.32	50	49	50	23	0-5	5-10	2-6
	39	56.8	546	1.79	59	54	57	18	0-5	0-5	2-6
	40	49.3	450	1.66	51	45	48	17	0-5	5-10	2-6
Till from the C.L. and adjacent areas	23	42.7	473	2.92	41	47	44	29	5-10	10-20	2-6
	30	48.2	492	2.26	48	49	48	23	0-5	5-10	2-6
	33	43.2	432	2.62	42	43	43	26	5-10	10-20	2-6
	44	56.3	527	2.32	57	53	55	23	2-5	5-10	2-6
	45	56.5	495	2.68	57	49	53	27	10-20	0-5	2-6
	46	50.1	390	2.05	51	39	45	21	5-10	5-10	2-6

1 Montmorillonite based on cation exchange capacity data
2 Montmorillonite based on surface area data
* Estimates based on x-ray diffraction patterns
** Average value of duplicate determinations
*** Average value of triplicate determinations

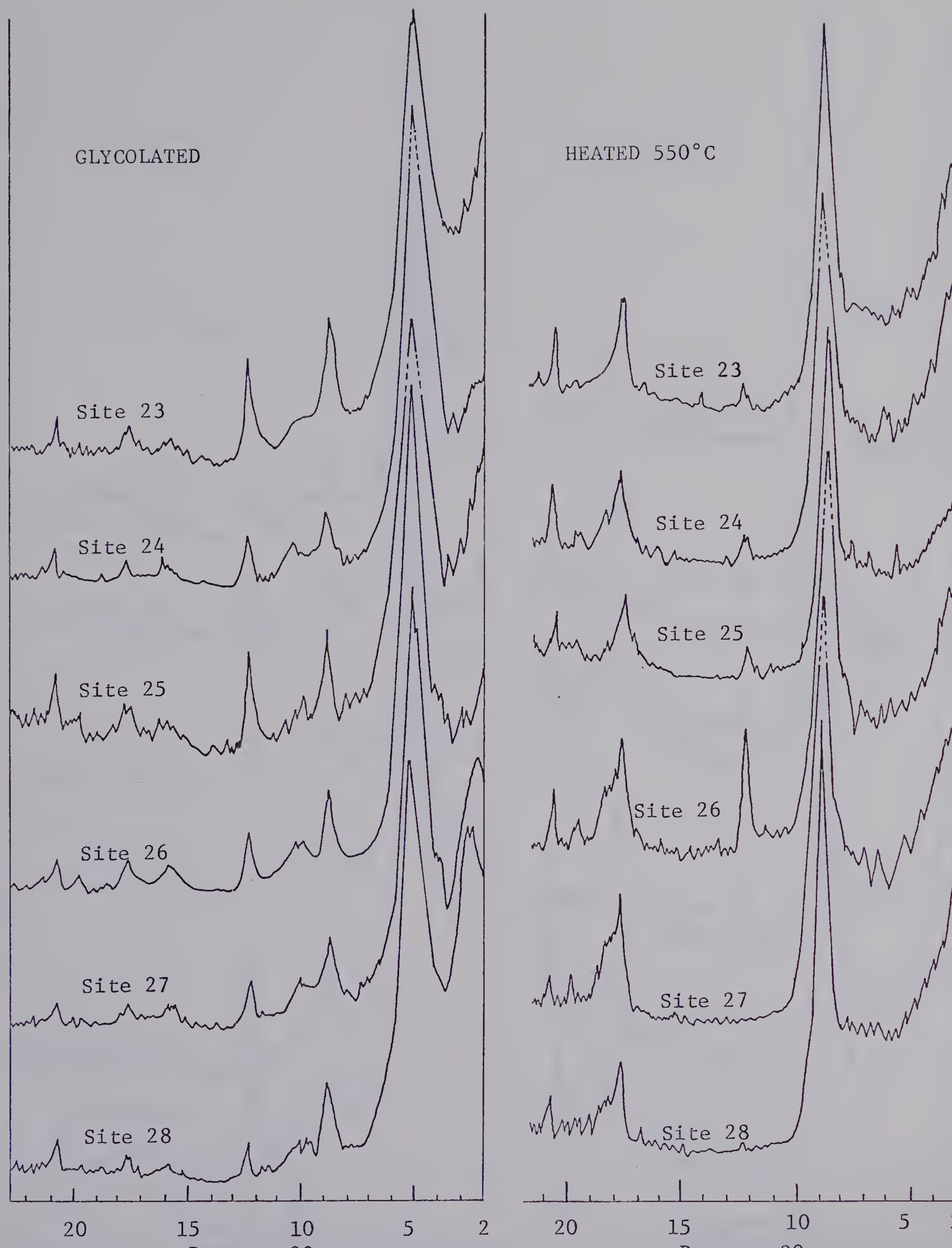

Figure IIc - X-ray Diffraction Patterns of Total Clay Separated from the Till Samples from the Chip Lake and Adjacent areas

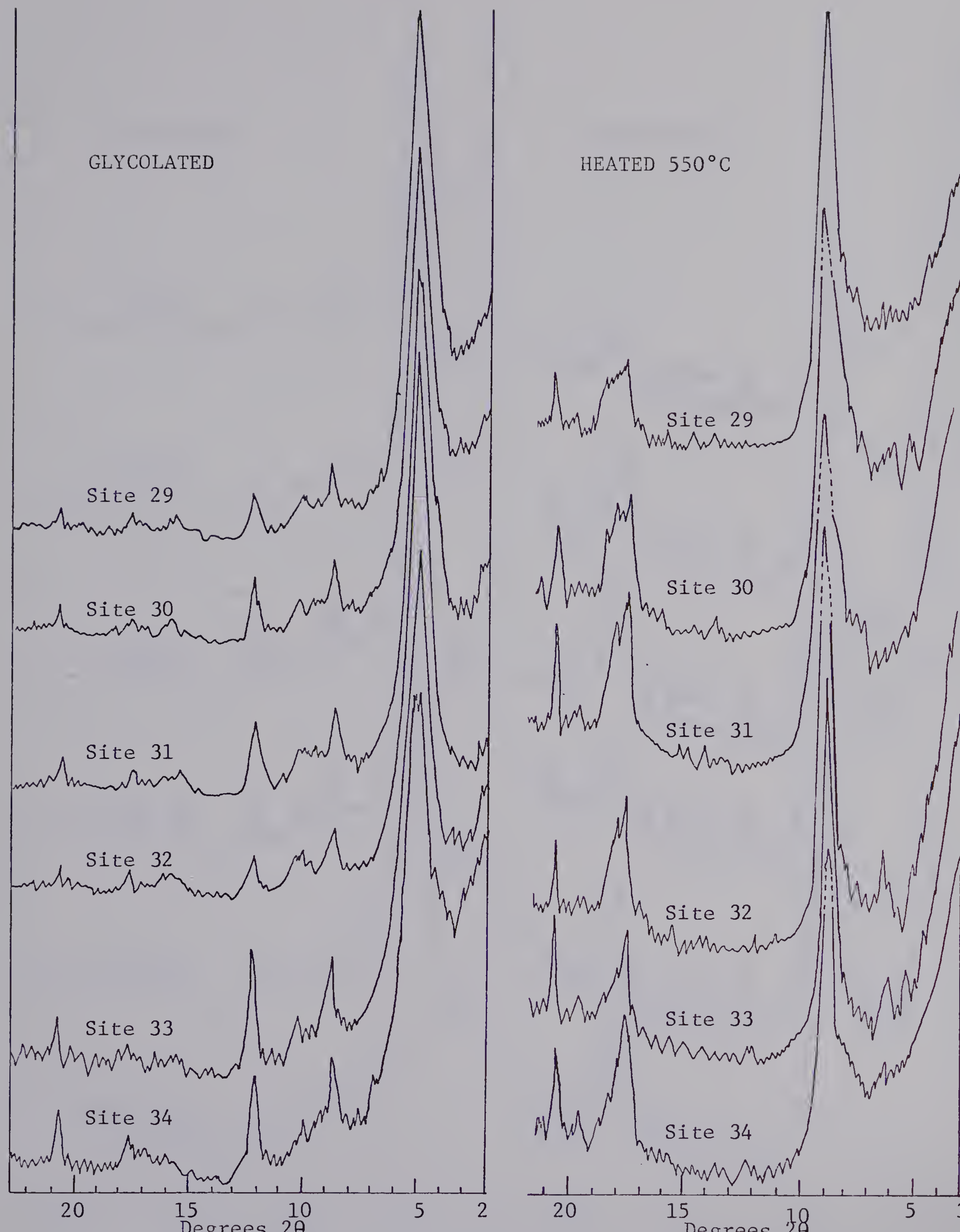

Figure IIIc - X-ray Diffraction Patterns of Total Clay Separated from the Till Samples from the Chip Lake and Adjacent areas

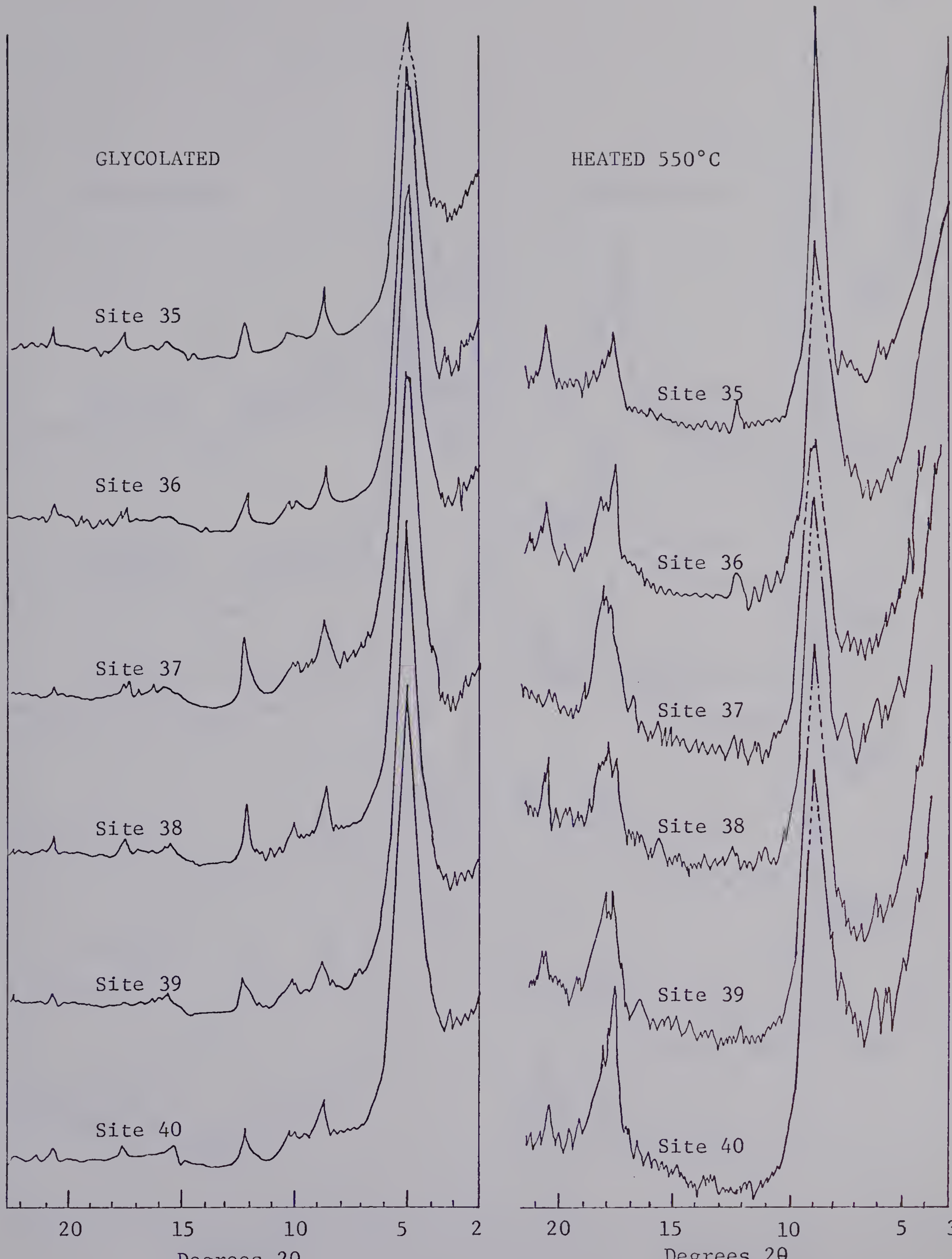

Figure IVc - X-ray Diffraction Patterns of Total Clay Separated from the Till Samples from the Chip Lake and Adjacent areas

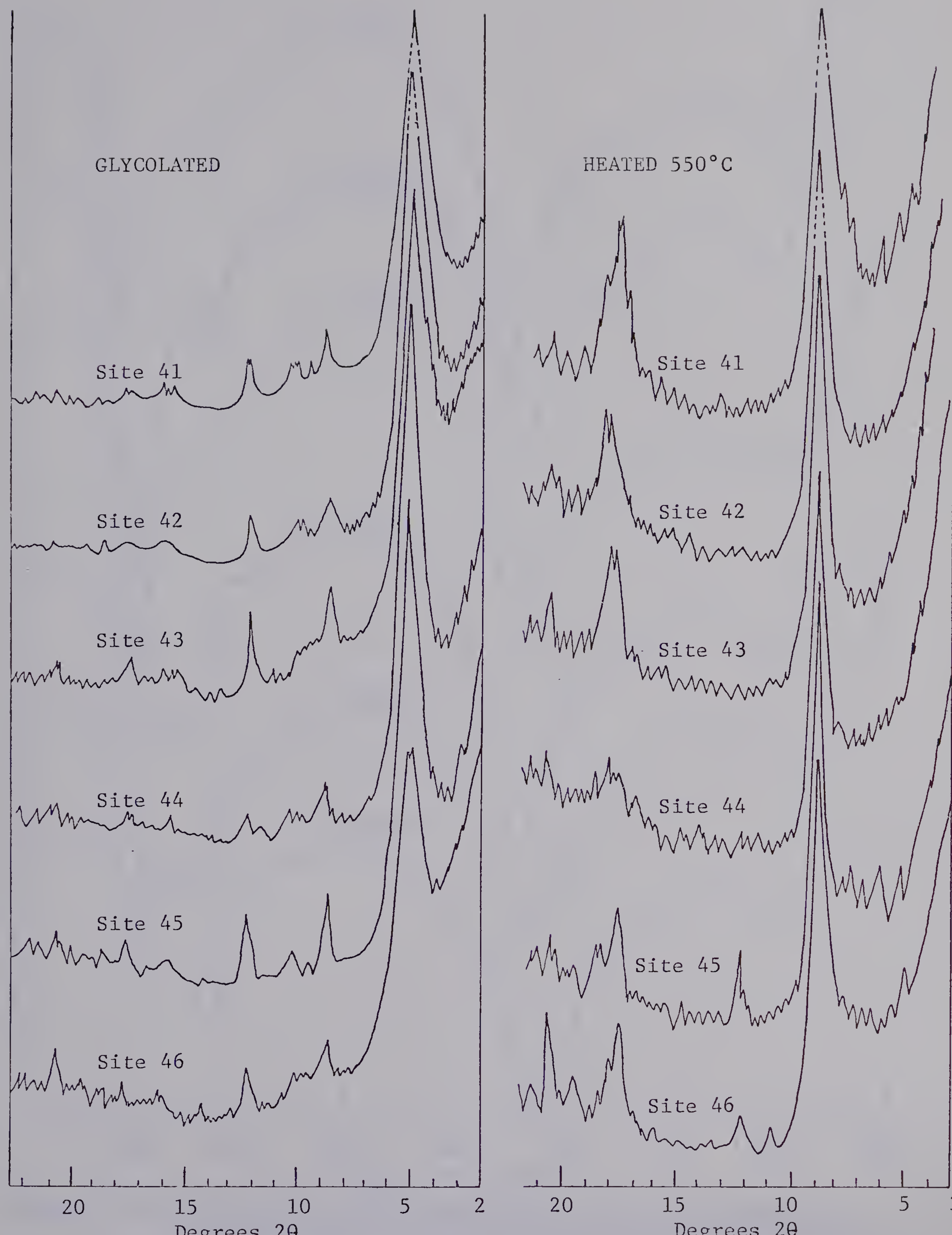

Figure Vc - X-ray Diffraction Patterns of Total Clay Separated from the Till Samples from the Chip Lake and Adjacent areas

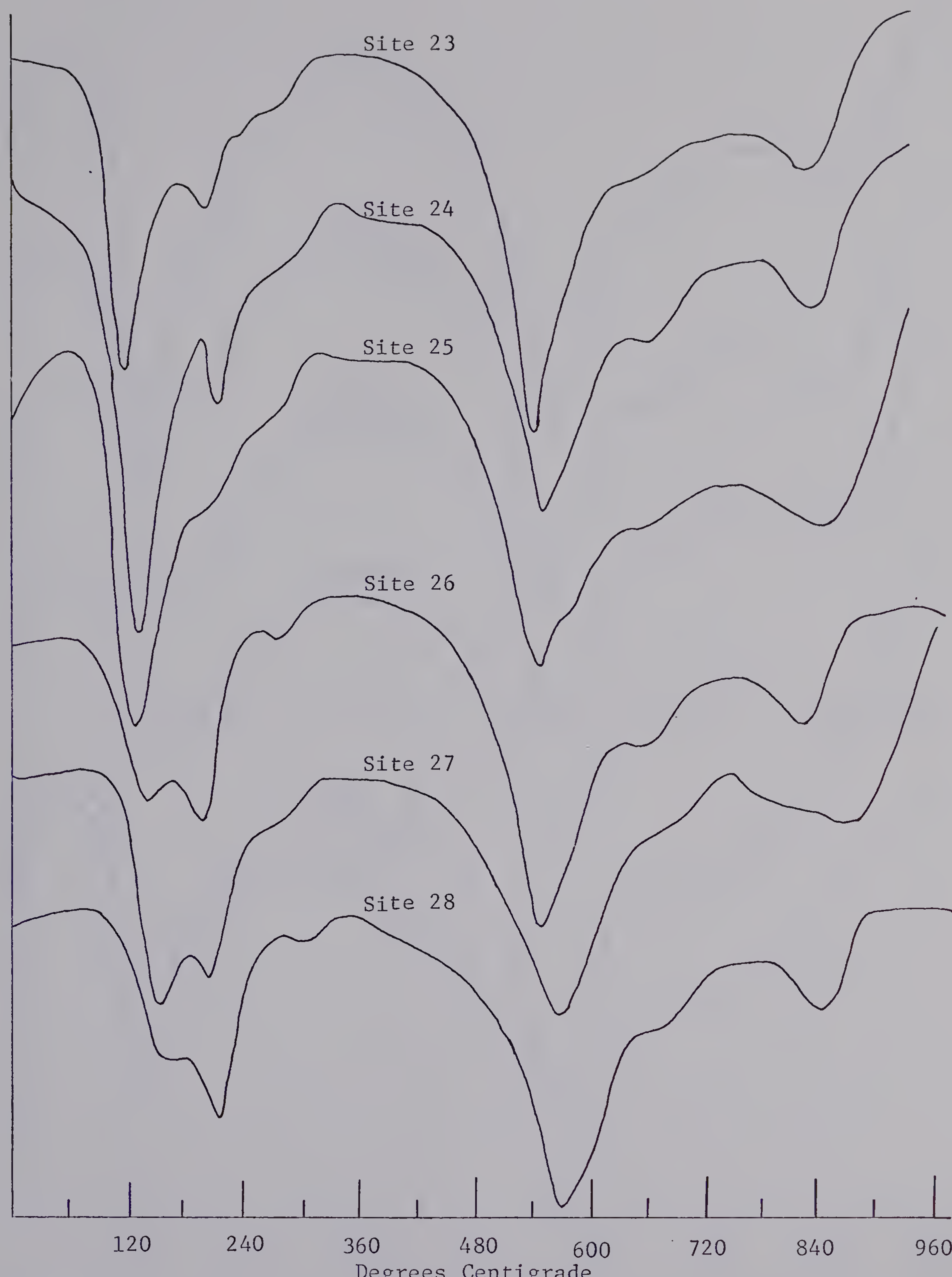

Figure VIc - Differential Thermographs of the Total Clay Fraction Separated from the Till Samples from the Chip Lake and Adjacent areas

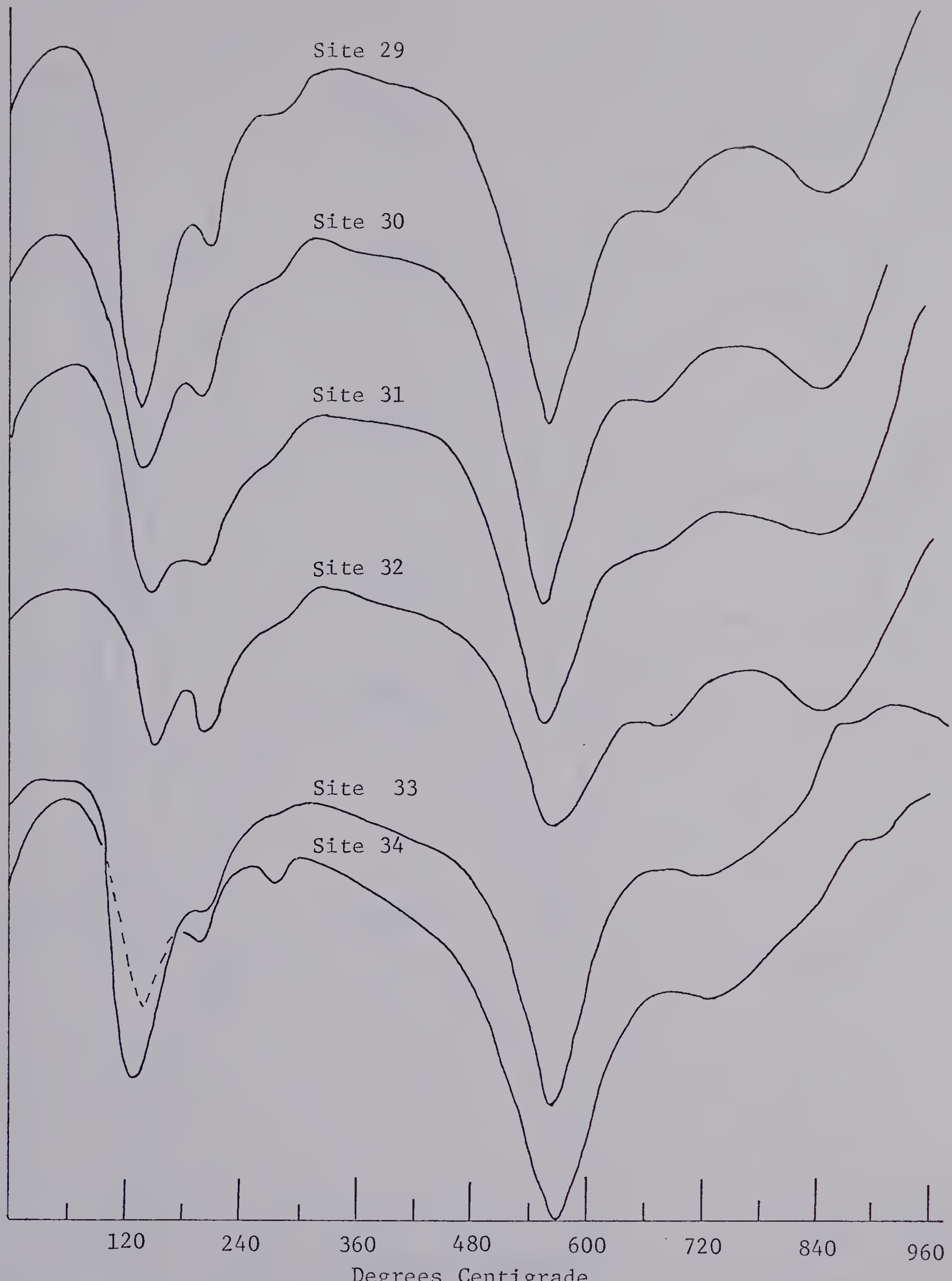

Figure VIIc - Differential Thermographs of the Total Clay Fraction Separated from the Till Samples from the Chip Lake and Adjacent areas

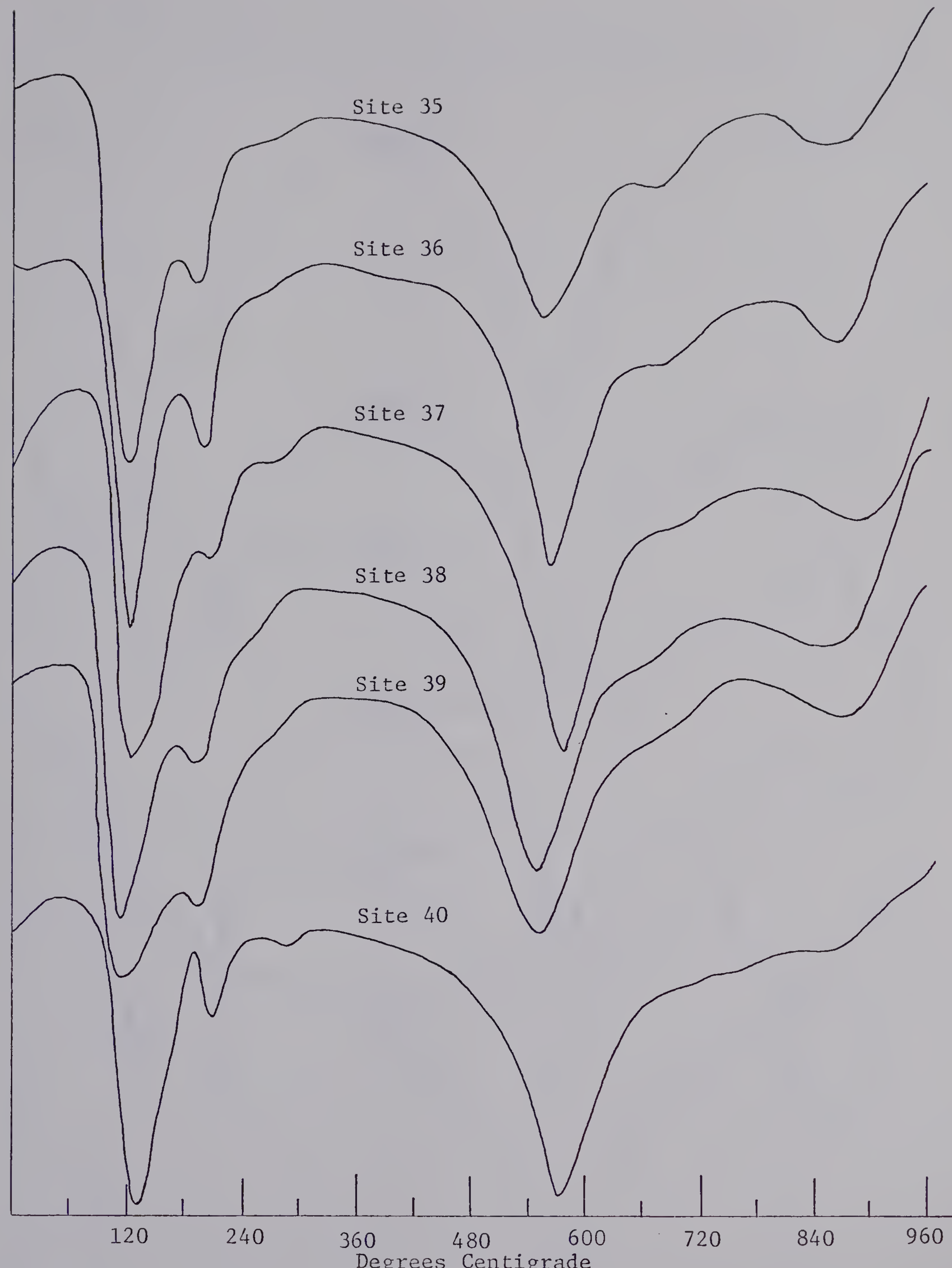

Figure VIIIc - Differential Thermographs of the Total Clay Fraction Separated from the Till Samples from the Chip Lake and Adjacent areas

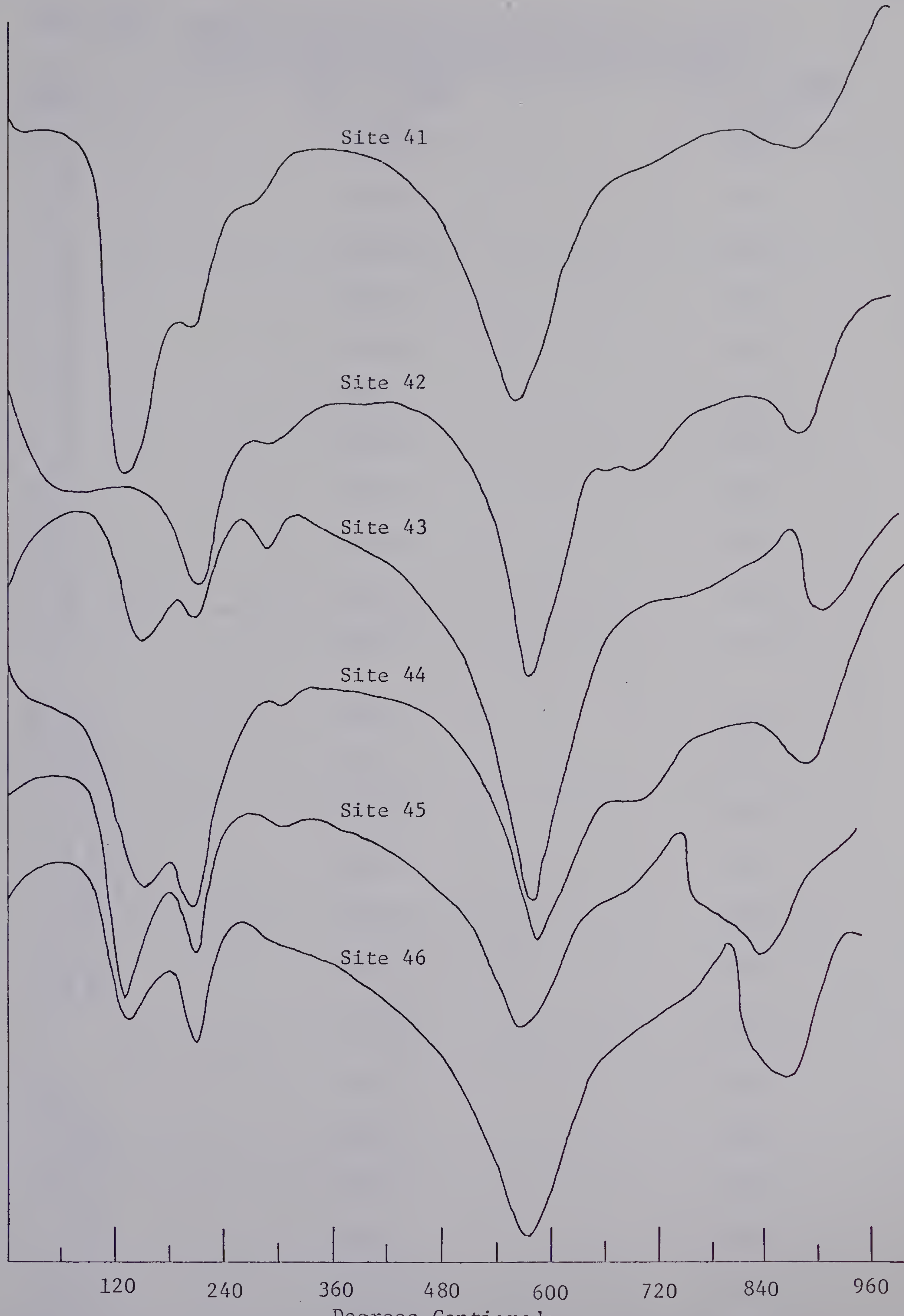

Figure IXc - Differential Thermographs of the Total Clay Fraction Separated from the Till Samples from the Chip Lake and Adjacent areas

TABLE XIXc - Light and Heavy Mineral Distribution of the Till Samples from the Chip Lake and Adjacent areas

Sample Number		Light Minerals (S.G.< 2.96) (%)	Heavy Minerals (S.G.> 2.96) (%)
24	Hubalta Till from the Chip Lake map area	99.13	0.87
25		99.13	0.87
26		99.18	0.82
27		99.24	0.76
31		99.22	0.78
34		98.87	1.13
36		98.89	1.11
38		99.09	0.91
41		99.20	0.80
42		98.92	1.08
43		98.47	1.53
28	Hubalta-Breton Till inter-grade from the Chip Lake map area	99.07	0.93
29		99.11	0.89
32		99.34	0.66
35		99.16	0.84
37		99.34	0.66
39		99.25	0.75
40		99.28	0.72
23	Tills from Chip Lake and adjacent areas	99.04	0.96
30		99.11	0.89
33		99.47	0.53
44		99.24	0.76
45		99.27	0.73
46		99.58	0.42

TABLE XXc - Quantitative Estimates for the Light Mineral Distribution of the Till Samples from the Chip Lake and Adjacent areas (S.G.< 2.96)

Sample Number		K_2O (%)	Na_2O (%)	CaO (%)	K Feldspar (%)	Soda-Calcic Feldspar (%)	Total Feldspar (%)	Quartz* (%)	Feldspar/Quartz Ratio
24	Hubalta Till from the Chip Lake map area	1.88	2.10	0.87	11	22	33	67	0.492
25		1.43	1.53	0.57	8	16	24	76	0.316
26		1.58	1.95	0.81	9	21	30	70	0.428
27		1.51	2.07	0.58	9	21	30	70	0.428
31		1.02	0.99	0.39	6	10	16	84	0.190
34		0.93	1.01	0.37	5	11	16	84	0.190
36		1.36	1.55	1.44	8	20	28	72	0.389
38		1.63	2.70	0.71	10	26	36	64	0.562
41		1.34	1.53	0.49	8	15	23	77	0.299
42		1.73	2.00	0.74	10	21	31	69	0.449
43		0.90	1.68	0.39	5	16	21	79	0.266
28	Hub.-Bn. Till intergrade	1.78	2.14	0.81	10	22	32	68	0.470
29		1.51	1.79	0.61	9	18	27	73	0.370
32		1.78	2.22	0.83	10	23	33	67	0.492
35		1.84	2.56	0.74	11	26	37	63	0.587
37		1.10	1.94	0.39	6	18	24	76	0.316
39		1.17	1.84	0.45	7	18	25	75	0.333
40		1.25	1.40	0.49	7	14	21	79	0.266
23	Till from the C.L. and adjacent areas	1.29	1.43	0.35	8	14	22	78	0.282
30		1.20	1.26	0.49	7	13	20	80	0.250
33		0.69	0.76	0.26	4	7	11	89	0.124
44		1.78	2.58	0.70	10	25	35	65	0.538
45		1.93	2.00	0.70	11	20	31	69	0.449
46		2.03	2.83	0.81	12	28	40	60	0.667

* Determined by difference